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Preface

The work reported here started in 1977 with a general assessment of the state-of-the-art in modeling human behavior in complex man-machine systems. It had been found that planning is an increasingly important task the nature of which, however, has not been well understood [Johannsen, Rouse, 1979].

Two subsequent experiments were accomplished in 1979-1981 in order to investigate the planning process of humans in a realistically simulated work environment. The experiments were run in an aircraft simulator at the FAT in F.R. Germany (Johannsen, Hillmann) whereas the data analyses were calculated in the United States (Rouse). Rouse started this work at the University of Illinois at Urbana-Champaign and continued it at his present affiliation, Georgia Institute of Technology, Atlanta.

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Abstract

Planning will become an increasingly central function for the human operator as automation takes over more and more of the manual tasks associated with man-machine systems. In order to understand and aid the human in this role, an experimental methodology for the study of human planning behavior is needed. Further, a model of the process by which the human plans is desirable. This report presents a methodology for studying planning and discusses the results of applying the methodology within two experimental investigations of planning behavior of aircraft pilots in normal, abnormal, and emergency situations. Beyond showing that the methodology yields consistent results, these experiments also produced new concepts in terms of a dichotomy between event-driven and time-driven planning, subtle effects of automation on planning, and the relationship of planning to workload and flight performance.

Kurzfassung

Planung wird eine zunehmend zentrale Funktion für den Menschen als Operateur werden, da die Automation mehr und mehr manuelle Aufgaben in Mensch-Maschine-Systemen übernimmt. Um den Menschen in dieser Rolle zu verstehen und zu unterstützen, wird eine experimentelle methodische Vorgehensweise für die Untersuchung des menschlichen Planungsverhaltens benötigt. Weiterhin ist ein Modell des Prozesses des menschlichen Planens wünschenswert. Dieser Bericht beschreibt eine methodische Vorgehensweise für die Erforschung der Planung und diskutiert die Ergebnisse, die bei der Anwendung der Methode gewonnen wurden, und zwar in zwei experimentellen Untersuchungen des Planungsverhaltens von Flugzeugpiloten in normalen, außergewöhnlichen und Notfallsituationen. Es wird gezeigt, daß die methodische Vorgehensweise folgerichtige Ergebnisse liefert. Außerdem ergaben die Experimente neue Konzepte bezüglich einer Zweiteilung zwischen ereignis- und zeitbedingter Planung, bezüglich sinnreicher Auswirkungen der Automation auf die Planung sowie für die Beziehung der Planung zur Beanspruchung und Flugleistung.

1. Introduction

In a recent paper [Johannsen and Rouse, 1979], the authors reviewed the problem of modeling human behavior in complex man-machine systems. One particularly important conclusion of this review was that planning will become an increasingly central function of the human as automation takes over more and more of the manual tasks. It was also concluded that the human's planning process is not very well understood. The purpose of the research summarized in this report has been to increase understanding in this area.

Previous researchers have certainly recognized the human's role as a planner in man-machine systems [Sheridan, 1976]. However, there appear to have been very few attempts to measure and model the human's planning process. Notable exceptions to this conclusion include several efforts in the field of artificial intelligence and cognitive science. Three especially important concepts have emerged. The first is that planning can be avoided if one employs a standard "script" [Schank and Abelson, 1977] or "frame" [Minsky, 1975] that specifies the likely sequence of events and appropriate actions within a particular domain. For example, one has a "driving to work" script that allows one to accomplish this task with a relatively low investment of effort.

Another important concept that has emerged is that of hierarchical planning [Sacerdoti, 1975; Weissman, 1976]. In a planning hierarchy, the depth of planning can range from broad and sketchy to narrow and concise. In this way, one can avoid investing effort in detailed planning until it is necessary. Once one accepts the idea of hierarchical planning, it is reasonably natural to become interested in the determinants of the level of the hierarchy in which a planner chooses to operate. This report addresses this issue.

The combination of scripts, frames, and hierarchical planning emphasizes a rather top-down view of planning where goals lead to subgoals, plans lead to subplans, and the process smoothly progresses. An alternative view is the "opportunistic" model of Hayes-Roth and Hayes-Roth [1979]. In this model, high-level and low-level aspects of planning compete for attention in a somewhat interrupt-driven manner. While one can view these interrupts as occurring randomly, the resulting perspective is of a rather disorderly process. A more palatable view is that "events" cause interrupts. The nature of these events is explored in this report.

The overall goal of the research discussed in this report has been to develop a methodology suitable for measuring planning activity and modeling the planning process of human operators in complex dynamic systems, in this case aircraft. This work has benefitted greatly from the concepts summarized in the above paragraphs. The main contribution of this work has been the development of a rigorous experimental methodology, its application to two experimental studies within a realistically complex man-machine system [Johannsen and Rouse, 1980, 1981], and the interpretation of experimental results in terms of concepts for modeling the process of planning.

2. Method

2.1 Subject Population

In the experiments, the planning process of aircraft pilots has been investigated. An HFB-320 Hansa Jet simulator at the Forschungsinstitut für Anthropotechnik (FAT) was employed [Holzhausen and Kühne, 1974].

Using this simulator, nine professional HFB-320 pilots flew several missions from cruise to touch down. Three pilots participated in a pilot study, another three pilots in Experiment I, and the last three pilots in Experiment II.

The subject population of Experiments I and II was highly homogenous, averaging just under 5000 flight hours each of which approximately one-third were in the HFB-320. The pilots had almost no or only little experience with flight simulators. The average age of the group was 39.

2.2 Flight Simulator

The HFB-320 Hansa Jet is a 5 - 12 passenger, twin engine jet used for both military and commercial purposes. It normally has a two-man crew.

The HFB-320 flight simulator at the FAT allows full maneuverability, is fixed base, and has no visual simulation of the outside view. The cockpit is an original mockup from the aircraft manufacturer. It is instrumented with conventional displays for flight, engines, and navigation as well as controls that include steering force simulation. Also, a fairly sophisticated autopilot as well as a flight director with V-bar indicators in the artificial horizon are available. However, some limitations are present as the flight instruments for the copilot, the controls in the overhead panel, and a simulation of waypoints for navigation are missing. These limitations restrict the possibilities for simulating emergency situations. Further, it was necessary to run the experiments with a second experimenter playing the combined role of the copilot and the air traffic controller.

A more detailed description of the HFB-320 simulator is given in Appendix A.

2.3 Flight Scenarios in General

2.3.1 Normal Scenario

Three flight situations were studied: 1) normal, 2) abnormal, and 3) emergency. The "normal" flight scenario N which was the basic one in these experiments is illustrated in Figure 1 with a plan view and a side view. There, eight flight phases are shown, namely: 1) Cruise, 2) Descent, 3) Holding, 4) Initial Approach, 5) Final Approach, 6) Landing, 7) Ground Roll, and 8) Cruise to Alternate. The overall mission of the N scenario lasted approximately 20 minutes when no cycles of the holding pattern or cruise to alternate were to be flown. No unusual events occurred. In Experiment I, the N scenario was flown with three cycles of the holding pattern and lasted approximately 32 minutes, whereas no holdings were flown in Experiment II. For more details, see Appendices B.1.1 and B.2.1.

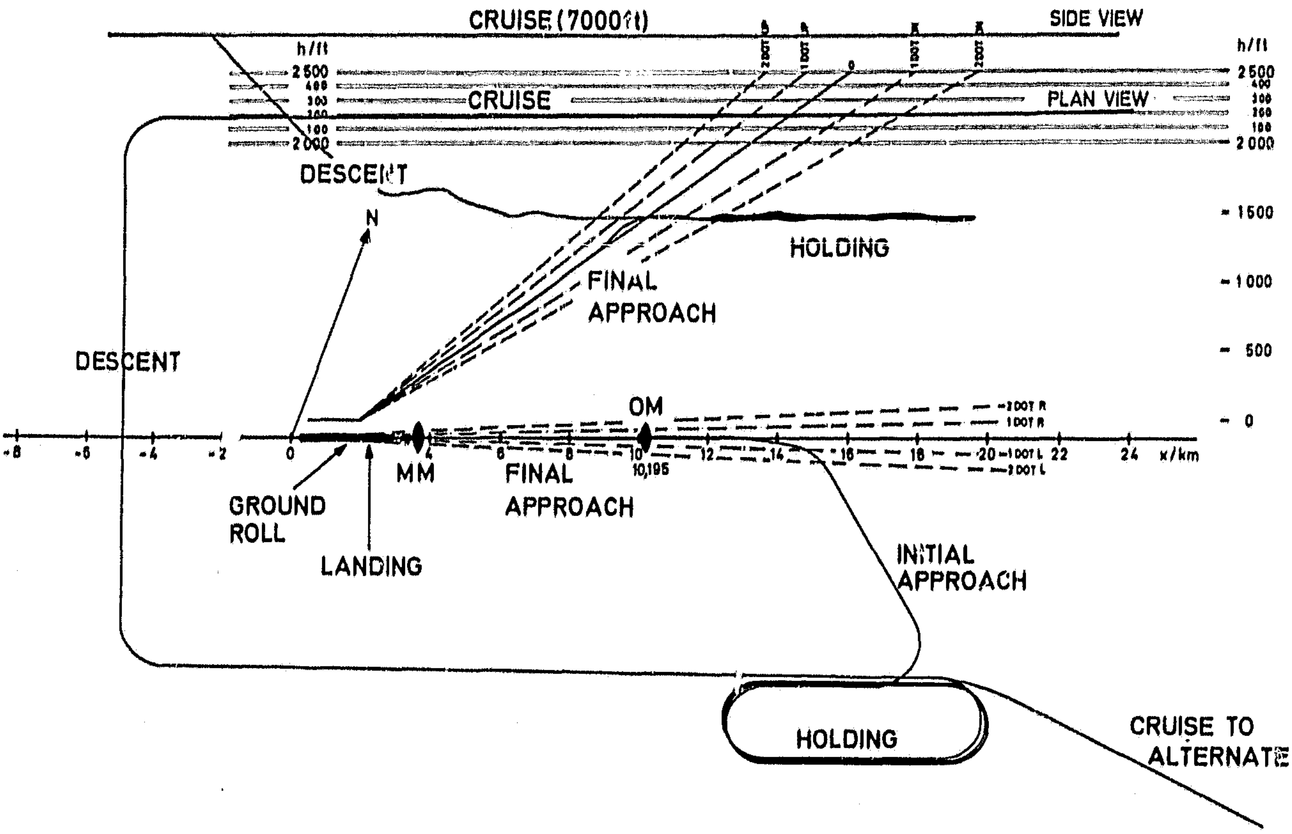

Figure 1: Course and flight phases of basic flight scenario (plan and side view)

The pilots were asked to use the flight director and the automatic throttle system in order to obtain more steady flight conditions. This request remained unchanged throughout all flight scenarios.

2.3.2 Abnormal Scenarios

The abnormal flight scenarios (denoted by A_1 and A_2) were characterized by procedural changes. In Experiment I, the pilots received information that the runway had been closed temporarily, snow removal was in progress, and that they were requested to enter a holding pattern. The information was given at two time instances, at 4.75 min after starting the experimental run, i.e., during Cruise, in scenario A_1, and at 13.75 min with a warning at 8.25 min ("snowfall expected") in A_2. This resulted in a holding pattern before the descent in scenario A_1 whereas the sequence of the flight phases in A_2 was the same as in the basic scenario N. During the holding patterns in A_1 and A_2, the additional flight phase (8) emerged as a possibility for the pilots, i.e., "Cruise to Alternate". Before completing the third cycle of the holding pattern, the pilots received information that the runway was "clear and wet" and that they could continue their approach. Due to the three cycles of the holding pattern, these abnormal flights lasted approximately 32 minutes.

In Experiment II, abnormality A_1 involved a temporary runway closure due to snow removal, which was announced 4.2 minutes into the flight and presented the possibilities of requiring the pilot to enter the holding pattern or to cruise to the alternate airport. Abnormality A_2 involved temporary CAT-III conditions due to a dense fog, which was announced 7.5 minutes into the flight and presented the same possibilities as abnormal situation A_1. While the possibilities of holding or cruising to an alternate were clearly shown on the map furnished to the pilot (and available in the cockpit), the abnormal situations were always resolved at the last minute and holding and cruising to an alternative always avoided. In this way, all flights were limited to 20 minutes.

For more details, see Appendices B.1.2 and B.2.2.

2.3.3 Emergency Scenarios

In Experiment I, the emergency flight scenarios (denoted by E_1 and E_2) were characterized by a failure of the right engine, namely, a shut-down. In case E_1, the failure occurred a short time before the pilot would have been requested to enter the holding pattern in the basic scenario. Of course, the holdings had to be omitted with a single engine failure, which resulted in a time duration of the whole mission of approximately 20 minutes. The other scenario E_2 included the same sequence of flight phases as the basic one (i.e., N) with the single engine failure occurring shortly after the aircraft was expected to pass the outer marker (see OM in Figure 1). In both cases, flight control was accomplished manually. Otherwise, the autopilot would have compensated for the engine failure, and the pilots would have been unable to detect it.

In Experiment II, emergency E_1 involved the failure of the right engine at 4.2 minutes into the flight. The failure was announced by an alarm in the cockpit similar to that in real HFBs. In this way, there was no problem with the pilot missing the failure, even in flights with autopilot. Emergency E_2 involved a severe loss of hydraulic pressure due to a total loss of hydraulic fluid, i.e., even the hand pump for the gear was inoperative and an emergency landing was requested. This failure was announced at 7.5 minutes into the flight by the alarm in the cockpit.

For more details, see Appendices B.1.3 and B.2.3.

2.4 Measures

2.4.1 Depth of Planning and Timeline

The objective of this study was to measure the planning process of pilots during the different flight situations just described. The notion of depth of planning has been introduced as the basic concept for this purpose. Depth denotes level of detail which can range from broad and sketchy to specific and concrete. The hypothesis was that planning with respect to a particular task need not be very deep if:

1) The amount of time until the task must be performed is large.
2) The task is not critical to mission success.
3) It appears that the environment will be "hospitable" to successfully completing the task (i.e., the probability of increased difficulty will be low).

However, if one or more of these conditions ceases to hold, then depth of planning will increase to the extent that the conditions are not satisfied. In other words, the depth of planning associated with a particular task will be very great if the task must be performed immediately, is critical to mission success, and may be more difficult than usual to accomplish.

Thus, the hypothesis is that depth of planning is affected by the three independent variables: time, criticality, and probability of increased difficulty. To evaluate this hypothesis, it was necessary to measure depth of planning as well as its three independent variables. The measures for difficulty and criticality will be described in Section 2.4.2.

For the first variable (i.e., time), a timeline indicating when things are supposed to happen was constructed for all flight scenarios. This was not only done for the beginning of the 8 flight phases but also for the beginning of three selected subtasks for each flight phase (see Table 1). The subtasks were chosen after discussions with aeronautical engineers and pilots in order to characterize a second more detailed level of each flight phase by means of typical examples (e.g., altimeter, localizer intercept, gear, crosswind).

Table 1: Timeline - Beginning of flight phases and subtasks for Experiment I

	N, E_2	E_1	A_1	A_2
1. Cruise	0 : 00	0 : 00	0 : 00	0 : 00
1.1 Approach procedure	6 : 15	6 : 15	6 : 15	6 : 15
1.2 Request to leave flight level	~2 : 00	~2 : 00	~2 : 00	~2 : 00
1.3 Fuel control (+ Power setting)	0 : 00	0 : 00	0 : 00	0 : 00
2. Descent	7 : 15	7 : 15	19 : 15	7 : 15
2.1 Obstacle clearance	7 : 15	7 : 15	19 : 15	7 : 15
2.2 Flight instruments	7 : 15	7 : 15	19 : 15	7 : 15
2.3 Altimeter	7 : 15	7 : 15	19 : 15	7 : 15
3. Holding	15 : 15	-	6 : 15	15 : 15
3.1 Track intercept	15 : 15	-	6 : 15	15 : 15
3.2 Traffic orders (+ information)	15 : 15	-	6 : 15	15 : 15
3.3 ATIS (e.g., runway condition, weather, QNH)	8 : 15	8 : 15	19 : 20	25 : 20
4. Initial Approach	26 : 45	15 : 15	26 : 45	26 : 45
4.1 Flaps	~28 : 00	~16 : 30	~28 : 00	~28 : 00
4.2 Localizer intercept	~28 : 30	~17 : 00	~28 : 30	~28 : 30
4.3 Glideslope intercept	~29 : 30	~18 : 15	~29 : 30	~29 : 30
5. Final Approach (OM inbound)	~29 : 45	~18 : 30	~29 : 45	~29 : 45
5.1 Gear	~29 : 30	~18 : 15	~29 : 30	~29 : 30
5.2 Weather minima	~31 : 15	~20 : 15	~31 : 15	~31 : 15
5.3 Flare	~31 : 20	~20 : 20	~31 : 20	~31 : 20
6. Landing (Flare + Touch down)	~31 : 15	~20 : 15	~31 : 15	~31 : 15
6.1 Crosswind	~31 : 15	~20 : 15	~31 : 15	~31 : 15
6.2 Runway condition	~31 : 15	~20 : 15	~31 : 15	~31 : 15
6.3 Passenger comfort	~31 : 15	~20 : 15	~31 : 15	~31 : 15

Table 1 (Continued):

	N, E_2	E_1	A_1	A_2
7. Ground Roll (after Landing)	~31 : 30	~20 : 30	~31 : 30	~31 : 30
7.1 On centerline	~31 : 30	~20 : 30	~31 : 30	~31 : 30
7.2 Speed brakes	~31 : 30	~20 : 30	~31 : 30	~31 : 30
7.3 Flaps	~31 : 30	~20 : 30	~31 : 30	~31 : 30
8. Cruise to Alternate	-	-	not occurring	not occurring
8.1 Approach procedure	-	-	4 : 45	13 : 45
8.2 Request to leave flight level	-	-	4 : 45	13 : 45
8.3 Fuel control (+ Power setting)	-	-	4 : 45	13 : 45

Depth of planning was measured by an online questionnaire technique*). As the flight proceeded, the pilots received verbal queries concerning the depth of planning associated with the present and future flight phases and the three selected subtasks for each flight phase. These queries were presented in a random order.

The flight task of the pilots should be disturbed as little as possible by the online questionnaire. Therefore, the pilots were thoroughly familiarized with the complete questions and possible responses during the instructions before the flights (see Appendices D and E*)). During the experiments, they only heard the short names of the flight phases and subtasks, e.g., "Final Approach", "Cruise", or "Track Intercept", "Crosswind". The answers were coded by numbers which were the only verbal responses of the pilots.

In Experiment I, the pilots responded with a verbal rating on a 5-point scale of depth of planning (see Table 2, and Appendix E for the actually used German version).

*) All instructions, ratings, and questionnaires actually used in the experiments were in German (see Appendix E).

Table 2: Questionnaire for depth of planning

Depth of Planning ↓		To what extent are you planning with respect to the flight phase or subtask?
	1	not at all
	2	generally aware of task
	3	overall qualitative assessment only
	4	specific information needs
	5	considering specific actions

The associated text explanations for the possible responses in Table 2 only served as an aid for getting a feeling for the scale. The queries normally occurred every 30 seconds with air traffic and navigational information supplied in the intervals (see Appendices B and C). If a depth rating indicated a detailed level of planning (i.e., 4 or 5), more specific queries concerning all three associated subtasks of that flight phase followed immediately, delaying the next query on another flight phase.

In Experiment II, depth ratings were made using a 10-point scale (see Appendices D and E). This change was made to lessen the occasional "chattering" between, e.g., ratings of 2 and 3 as obtained in the first experiment with the 5-point scale. Depth ratings were only made for flight phases 4, 5, and 6 (Initial Approach, Final Approach, and Landing) in the second experiment. These 3 phases with their 9 subtasks constituted a set of 12 possible queries to the pilot. All queries were randomly and independently chosen from the set of 12, with the exception that the 3 flight phases were twice as likely to be chosen as the 9 subtasks. Queries occurred every 20 seconds with air traffic and navigational information supplied in the intervals. Thus, with 20 minute flights and 3 questions per minute, there were 60 questions per flight, 8 for each flight phase and 4 for each subtask.

For the data analysis, two measures for depth of planning were derived from the raw data: average depth and frequency of depth above threshold. The mean $\bar{D}$ was calculated as the average depth. The frequency measure has been defined as $p(D \geq D_o)$, i.e., the number of depth ratings D which were above a certain threshold D_o were counted.

2.4.2 Probability of Increased Difficulty and Criticality

The probability of increased difficulty has been hypothesized to be one of the independent variables affecting depth of planning (see Section 2.4.1). This variable was also measured by an online questionnaire technique. The pilots were asked to rate the probability of increased difficulty of the task just mentioned, given the current situation and state of the aircraft. They only heard the short name "increase of difficulty" for the queries which followed immediately after the pilots responded to depth of planning. The answers were also coded by numbers of a 5-point scale (see Table 3 and Appendix E). The probability of increased difficulty was not measured during the second experiment because of its high correlation with depth of planning (see Section 3.1.2).

Table 3: Questionnaire for probability of increased difficulty

	Expected increase of difficulty?
1	none
2	minor
3	moderate
4	considerable
5	very considerable

Data for criticality, another independent variable of depth of planning, were collected off-line by using separate subjective scales for all flight phases and subtasks. The pilots were asked: "How important is each of the following flight phases and subtasks relative to the accomplishment of the overall mission?" An excerpt of the subjective scales for criticality assessment, which had to be cross-marked by the pilots, is shown in Figure 2. The order of the flight phases and subtasks for the complete set of scales is the same as that shown in Table 1 for the timeline (see also Appendix E).

The mean $\bar{C}$ was calculated as the average criticality for the data analysis.

completely unimportant	very important	
______________________		4. Initial Approach
______________________		4.1 Flaps
______________________		4.2 Localizer intercept
______________________		4.3 Glideslope intercept

Figure 2: Excerpt of subjective scales for criticality

2.4.3 Workload

Dependent variables in the experiment included not only depth of planning but also workload and performance. After each flight of approximately 20 or 32 minutes, the pilots estimated their experienced workload, separately for each of the flight phases. They used appropriate subjective rating scales [Johannsen, Pfendler, and Stein, 1976; Pfendler and Johannsen, 1977], similar to those for criticality, which had to be cross-marked. The subjective workload scales are shown in Figure 3 and Appendix E.

The mean $\bar{W}$ was calculated as the average workload for the data analysis. Strictly, nonparametric statistics would be more

Pilot: No.: Date: Time:

How strongly did you feel subjectively strained by the work load?

Please, give the answers separately for the 7 flight phases by cross-marking the following scales.

Cruise

very low effort	low effort	medium low effort	medium effort	medium high effort	high effort	very high effort

Descent

very low effort	low effort	medium low effort	medium effort	medium high effort	high effort	very high effort

Holding

very low effort	low effort	medium low effort	medium effort	medium high effort	high effort	very high effort

Initial Approach

very low effort	low effort	medium low effort	medium effort	medium high effort	high effort	very high effort

Final Approach

very low effort	low effort	medium low effort	medium effort	medium high effort	high effort	very high effort

Landing

very low effort	low effort	medium low effort	medium effort	medium high effort	high effort	very high effort

Ground Roll

very low effort	low effort	medium low effort	medium effort	medium high effort	high effort	very high effort

Figure 3: Subjective workload scales

appropriate but the pragmatic approach followed here seemed to be feasible. This argument has been adopted for the analysis of all data from online questionnaires and off-line subjective scales, i.e., for depth of planning D, criticality C, and workload W.

2.4.4 Performance

Extensive objective flight performance data was collected. The first approach was to consider seven performance tolerances. Two tolerances related to glideslope and localizer deviations at a height of 200 ft. The remaining five tolerances concerned touch down and included: longitudinal position, lateral position, sink rate, bank angle, and pitch angle. The measure "number of performance tolerances exceeded" was evaluated only for Experiment I. Its drawback is the fact that an assessment of performance is only given for the two flight phases Final Approach and Landing.

No single measure of performance seemed appropriate for the entire flight. However, the pilot's control signals in terms of elevator, aileron, and rudder angles can be viewed as indirect measures of performance. This is similarly true for the attitude signals in terms of pitch and roll angles. Certainly, any deviation from the desired flight path has to be corrected by using one of these controls and changing the attitude of the aircraft. However, these controls vary even for flights that stay exactly on the desired flight path. Thus, a baseline is needed with which to compare measures of control activity and attitude. A good choice is to use the same measures applied to the autopilot's activities as a baseline.

As a result of this consideration and after some experimentation with data mainly from the first experiment (see below), the square roots of sums of variances, with respect to time-varying means, integrated over flight phases j and divided by their time duration T_j were chosen as scalar performance measures for both, control actions (σ_C) and attitude (σ_A), e.g., for control:

$$\sigma_{C_j} = \frac{1}{T_j} \sum_{t=t_{oj}}^{t_{oj}+T_j} \sqrt{\sigma_1^2(t) + \sigma_2^2(t) + \sigma_3^2(t)} \, . \qquad (1)$$

The variance for a particular control $u_i(t)$ over a time window of length T = 10 s is given by the equations:

$$\sigma_i^2(t) = \frac{1}{T-1} \sum_{\tau=t-\frac{T}{2}}^{\tau=t+\frac{T}{2}} [u_i(\tau) - \bar{u}_i(\tau)]^2, \qquad (2)$$

$$\bar{u}_i(t) = \frac{1}{T} \sum_{\tau=t-\frac{T}{2}}^{\tau=t+\frac{T}{2}} u_i(\tau). \qquad (3)$$

The sum of variances of elevator, aileron, and rudder angles was taken for control actions. The variances of pitch and roll angles were calculated using equations similar to those above and summed for the attitude measure σ_{A_j}.

Some experimentation with the performance data was undertaken before deciding to use the above equations. The RMS-values (root-mean-square) were compared with the σ measures as shown in Equation (1). This was done graphically. In case of the σ measures, the square root from Equation (1) was illustrated as a function of time. Examples are shown in Figures 4 and 5 where the manual control activity (Fig. 5) has been contrasted with the autopilot's activity as a baseline (Fig. 4). It can be seen that the latter has been much more strongly determined by the flight course. The area under the curve corresponds to the measure of Equation (1), e.g., $\sigma_{C_4} = I4/\Delta T4$ (see Fig. 5). The comparison between the σ measures and the RMS-values showed that the inclusion of the means which are determined by the flight course was misleading in case of the RMS-values, especially as these are also included in the baseline activities with autopilot.

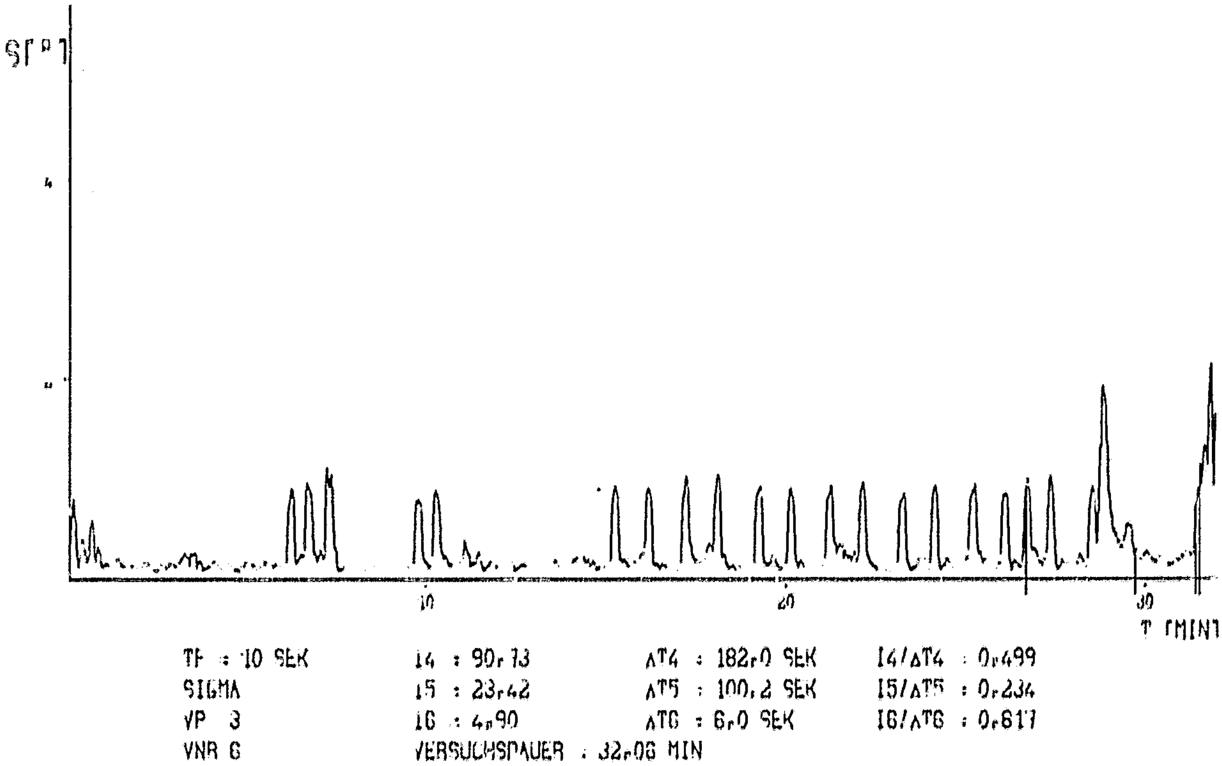

Figure 4: Example of autopilot control activity as a function of time for subject S_3 of Experiment I

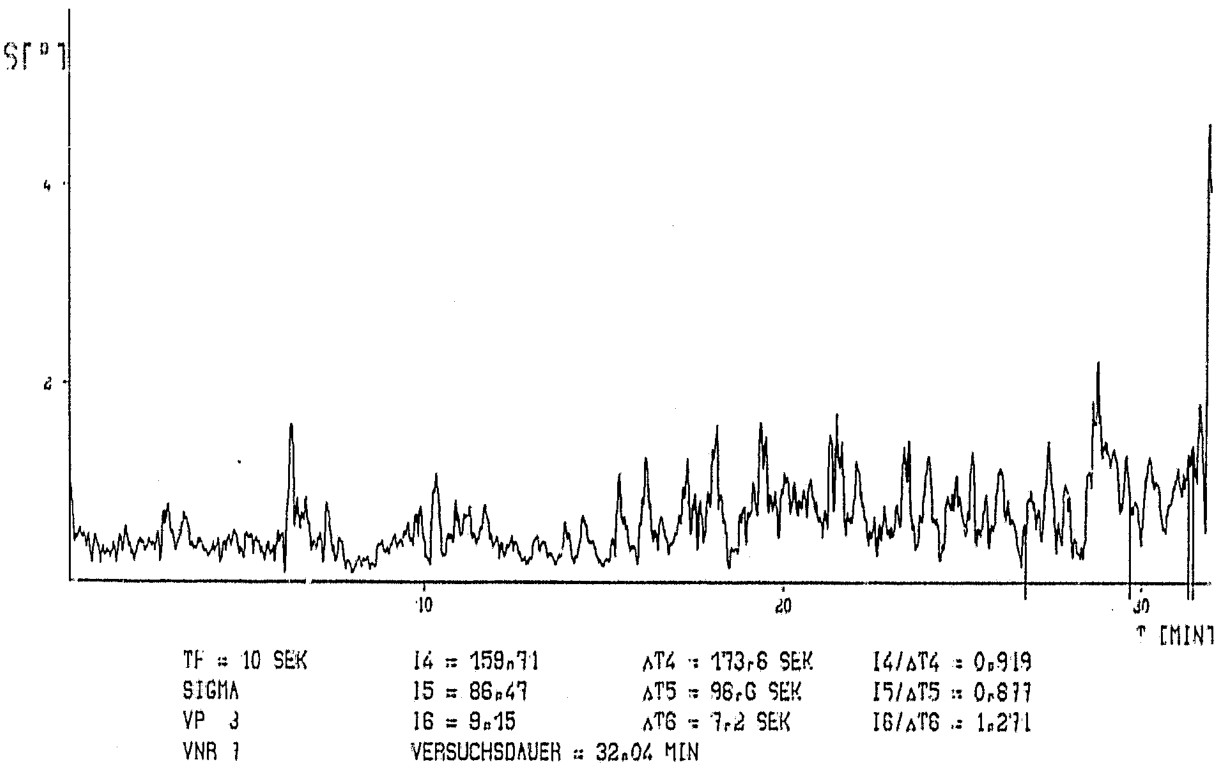

Figure 5: Example of manual control activity as a function of time for subject S_3 of Experiment I

Another experimentation was concerned with the length of the time window; see Equations (2) and (3). It was varied with the values T = 10 s, 20 s, and 30 s. The results showed that the averaging effect was too strong with the longer time windows.

The last experimentation with the data tried to explore whether a measure without averaging the control and attitude signals would be more appropriate. Instead of Equation (2), the following functions were calculated:

$$u_{\Delta i}^2(t) = [u_i(t) - \bar{u}_i(t)]^2 \tag{4}$$

where $\bar{u}_i(t)$ is the mean over T = 10 s as in Equation (3). Then, the following performance measure for the control actions during the flight phases j was taken, as opposed to Equation (1):

$$\Delta_{C_j} = \sqrt{\frac{1}{T_j} \sum_{t=t_{oj}}^{t_{oj}+T_j} [u_{\Delta 1}^2(t) + u_{\Delta 2}^2(t) + u_{\Delta 3}^2(t)]} \ . \tag{5}$$

The attitude measure Δ_{A_j} was calculated similarly. The difference between these Δ measures and the σ measures as shown in Equation (1) will be discussed in Section 3.2.2.

An additional measure was calculated for the "Final Approach" which was the combined RMS-value of the localizer and glide-slope (LOC/GS) deviations. The purpose of this measure was to consider the real errors observed during this flight phase. A comparison with the σ_A measure can also be found in Section 3.2.2.

2.5 Experiments

2.5.1 Pilot Study

The experimental studies have been accomplished in three parts, i.e., a pilot study, Experiment I, and Experiment II. In this section, some general information and the experimental designs will be given. The experimental procedures will be described in Appendix C.

First, a pilot study utilizing 3 subjects was performed to test the feasibility of the flight scenarios and questionnaires. Several modifications were made during and after these tests concerning the flight simulator, the aquisition of performance data, the procedures and instructions for the flight scenarios, the questionnaires, and the computer-aiding for the experimenter handling the online queries.

2.5.2 Design of Experiment I

Another 3 subjects participated in Experiment I. During these flights, data on the planning process, probability of increased difficulty, and flight performance as explained in Section 2.4 were collected. The treatments for the 3 subjects were the 3 flight scenarios which are described in Section 2.3, i.e., normal (N), abnormal (A), and emergency (E).

With one repetition per flight scenario, a replicated Latin Square design resulted. The experimental design actually used is shown in Table 4. It deviates from the Latin Square design by the additional tests $T_1(N_{01})$ and $T_5(N_{02})$. These tests were introduced as a reference for the basic flight scenario without online questionnaires, thereby allowing evaluation of the extent to which the questionnaires disturbed the pilots. The basic flight scenario itself was not changed for all tests N_{01}, N_{02}, N_1, and N_2. The other flight scenarios (A_1, A_2, E_1, and E_2) were those explained in Sections 2.3.2 and 2.3.3. In both abnormal situations, A_1 and A_2, the autopilot was used whereas all other flights were flown manually.

Table 4: Experimental Design for Experiment I

Subjects \ Tests	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
S_1	N_{01}	A_1	E_1	N_1	N_{02}	E_2	A_2	N_2
S_2	N_{01}	E_1	N_1	A_1	N_{02}	N_2	E_2	A_2
S_3	N_{01}	N_1	A_1	E_1	N_{02}	A_2	N_2	E_2

2.5.3 Desigr of Experiment II

Three other subjects participated in the Experiment II. During the flights, depth of planning and flight performance were measured as explained in Section 2.4. The treatments for the 3 subjects were the 5 flight scenarios N, A_1, A_2, E_1, E_2 which are described in Section 2.3, combined with 2 levels of automation, i.e., manual (M) and autopilot (A). The 5 x 2 factorial experimental design actually used is shown in Table 5 with tests T_1 through T_{10}. The test T_{11} was

Table 5: Experimental design for Experiment II

Subjects \ Tests	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}
S_1	N_M	A_{1A}	E_{1M}	A_{2A}	E_{2M}	N_A	A_{1M}	E_{1A}	A_{2M}	E_{2A}	ME_M
S_2	N_M	E_{1A}	A_{1M}	E_{2A}	A_{2M}	N_A	E_{1M}	A_{1A}	E_{2M}	A_{2A}	ME_M
S_3	N_M	A_{1A}	E_{1M}	A_{2A}	E_{2M}	N_A	A_{1M}	E_{1A}	A_{2M}	E_{2A}	ME_M

added in order to investigate the influence of multi-events (ME) during manual flight control (M). This scenario was a combination of the scenarios E_1, A_1, and E_2. An engine failure (E_1) occurred at 4.2 minutes into the flight, followed by a runway closure (A_1) at 5.2 minutes and a hydraulic failure (E_2) at 7.5 minutes (see also Appendix B.2.3).

3. Results

3.1 Experiment I

3.1.1 Depth of Planning, Workload, and Performance

Tables 6 and 7 summarize the overall results of Experiment I. While the abnormal scenarios (A_1 and A_2) resulted in the highest average depth of planning ($\bar{D}$) and the largest value of $p(D \geq 4)$, the emergency scenarios (E_1 and E_2) resulted in the highest average workload ($\bar{W}$) and largest values of σ_C and σ_A. From these results, one might conjecture that abnormalities require more planning than emergencies, perhaps because there are usually fixed procedures for dealing with "standard" emergencies while procedures for coping with abnormalities are typically more ambiguous. Unfortunately, in Experiment I the differences between abnormal and emergency scenarios were confounded with the use of autopilot for the abnormal scenarios and manual control for the emergency scenarios. Thus, it might be that the higher workload due to manual control during the emergencies precluded planning. This confounding of independent variables was eliminated in Experiment II.

Considering the differences among flight phases (Table 7), it appears that Initial Approach, Final Approach, and Landing are most interesting from a combined perspective of $\bar{D}$, $\bar{C}$, and $\bar{W}$. This result motivated the change in Experiment II such that depth of planning queries were only made for these phases and their subtasks. In this way, more measurements were obtained for the most interesting aspects of the flight.

Table 6: Results vs. scenario for Experiment I

SCENARIO	$\bar{D}$	p(D≥4)	$\bar{W}$	σ_C	σ_A
N_{01}	-	-	3.51	0.62	2.05
N_1	2.25	.057	3.60	0.75	2.36
A_1	2.72	.201	3.30	0.39	1.32
E_1	2.15	.094	4.61	1.13	3.05
N_{02}	-	-	3.24	0.75	2.24
N_2	2.41	.078	3.87	0.71	2.15
A_2	2.69	.183	2.62	0.45	1.25
E_2	2.29	.107	4.03	0.91	2.68

Table 7: Results vs. flight phase for Experiment I

FLIGHT PHASE	$\bar{D}$	p(D≥4)	$\bar{C}$	$\bar{W}$	σ_C	σ_A
Cruise	2.50	.125	5.21	1.43	0.44	1.33
Descent	2.42	.034	6.02	2.22	0.39	1.47
Holding	2.44	.086	5.54	2.65	0.51	2.15
Initial App.	2.69	.064	7.13	3.30	0.84	3.39
Final App.	2.78	.183	8.37	5.05	0.65	1.63
Landing	2.42	.130	8.48	6.30	1.37	2.72
Ground Roll	1.71	.081	5.92	4.63	-	-
Cruise to Alt.	3.60	.600	7.82	-	-	-

3.1.2 Relationships Among Measures

In an attempt to determine whether or not $\bar{D}$, $\bar{C}$, $\bar{W}$, etc. were unique measures, the correlation between each pair of measures was calculated. Using the results in Table 6, three significant ($p<.05$) correlations were found: $\bar{W}$ and σ_C ($r=.863$); $\bar{W}$ and σ_A ($r=.877$); and σ_C and σ_A ($r=.978$). For the results in Table 7, there were two significant correlations: $\bar{C}$ and $\bar{W}$ ($r=.831$) and $\bar{W}$ and σ_C ($r=.851$). While the other correlations among $\bar{C}$, $\bar{W}$, σ_C and σ_A were all reasonably large, the small number of degrees of freedom associated with the highly aggregated measures in Table 7 made $p<.05$ difficult to achieve. A more fine-grained correlation analysis was performed for Experiment II and is discussed in Section 3.2.2.

It is particularly interesting that $\bar{D}$ was not significantly correlated with $\bar{C}$, $\bar{W}$, σ_C, or σ_A. This result is certainly consistent with the discussion in Section 3.1.1. A possible explanation for this result will be provided in Section 4.1.

The correlation between depth of planning and probability of increased difficulty was found to be $r=.601$ ($p<.01$). This result as well as logistical reasons dictated the decision to omit probability of increased difficulty as a variable in Experiment II.

3.1.3 Time Histories of Depth of Planning

Considering the six scenarios that included depth of planning assessments, eight flight phases, and three pilots, well over 100 time histories of depth of planning were collected. However, as noted in Section 3.1.1, depth of planning was greatest for the abnormal scenarios (A_1 and A_2). Therefore, in the interest of brevity, discussion of the time histories of depth of planning will be limited to those of one pilot for the A_1 and A_2 scenarios. These time histories are shown in Figures 6 and 7 for the flight phases Initial Approach, Final Approach, and Landing.

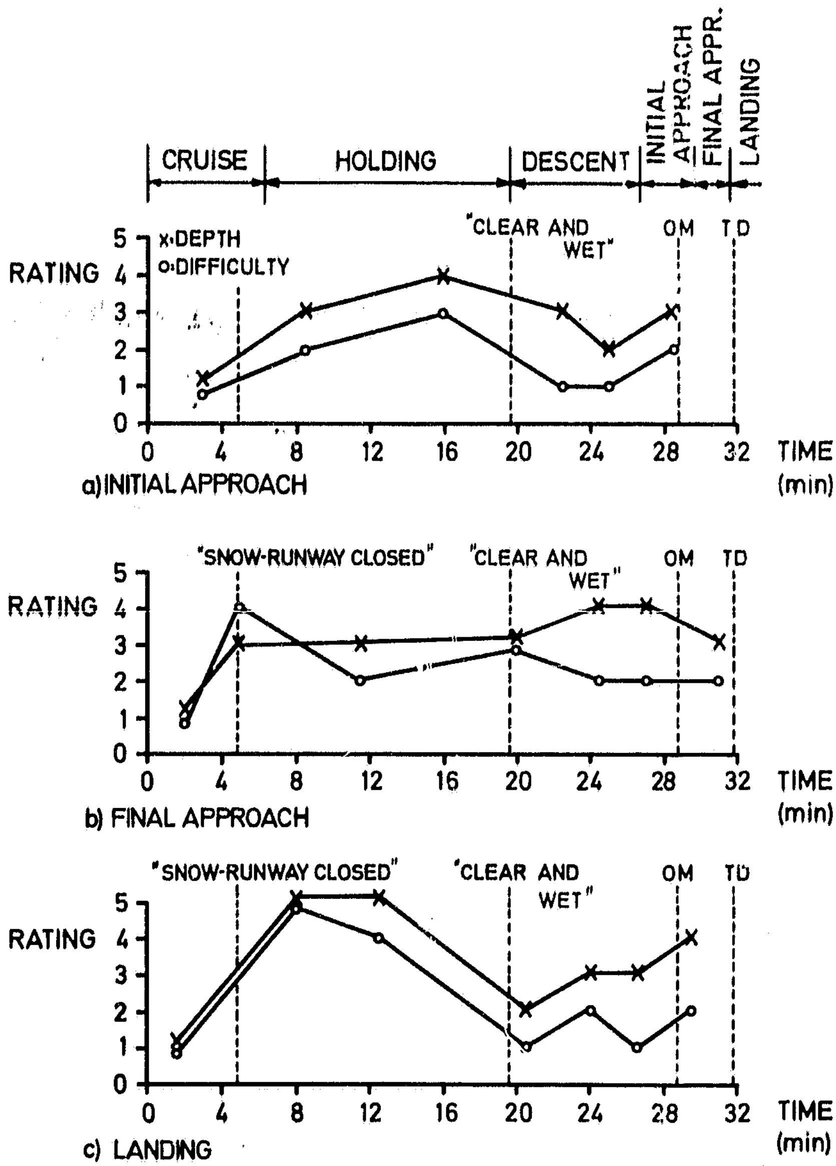

Figure 6: Depth and difficulty ratings for a) Initial Approach, b) Final Approach, and c) Landing for A_1

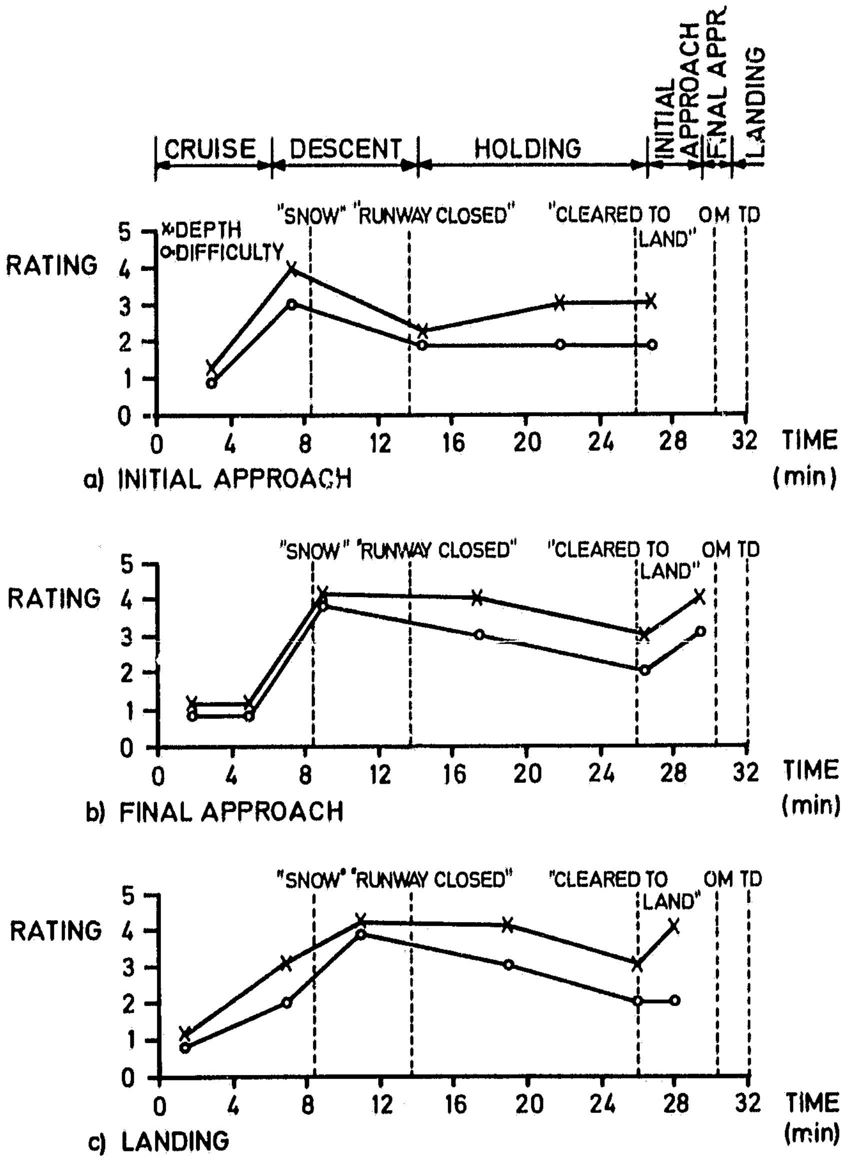

Figure 7: Depth and difficulty ratings for a) Initial Approach, b) Final Approach, and c) Landing for A_2

For the time histories shown in Figures 6 and 7 which are reasonably typical, a few straightforward conclusions are possible. First, as pointed out in the correlation analyses (Section 3.1.2), depth of planning is highly correlated with probability of increased difficulty. Although, admittedly, this relationship may have been significantly influenced by the pilot having to provide depth and difficulty ratings at the same instant. On the other hand, depth of planning appears to have been only weakly related to criticality. Perhaps a criticality measure conditioned on particular events (e.g., snow) might be a better predictor of depth of planning. Nevertheless, the results for difficulty and criticality noted in this paragraph led to their receiving much less emphasis in Experiment II.

Considering planning as it is affected by the time remaining until the flight phase in question begins, Figures 6 and 7 as well as many other time histories lead to a particularly interesting conclusion. There appears to be two types of planning: event-driven and time-driven. Event-driven planning is evidenced by increases in depth in response to events such as the report of "snow - runway closed" for A_1 in Figure 6. Time-driven planning occurs as the flight phase of interest is approached, as shown in four of the six time histories in Figures 6 and 7.

The differences between event-driven and time-driven planning might be characterized by defining time-driven planning as monitoring the following of a script while event-driven planning reflects the updating of the script because of an unanticipated situation. This conceptualization be considered in more detail in Sections 3.2.3. and 4.1.

3.2 Experiment II

As noted in Section 2.5.1, Experiment II was the third of a three-part series of experimental investigations. As such, Experiment II was carefully designed to test the hypotheses and conjectures which emerged from the pilot study and Experiment I. Consequently, the analysis of the data from Experiment II was much more rigorous and fine-grained. The results to be presented in the following sections are based on Analysis of Variance and, when multiple comparisons are discussed, Duncan's Multiple Range Test (see, e.g., [Afifi and Azen, 1972; Montgomery, 1976]).

3.2.1 Depth of Planning, Workload, and Performance

Tables 8 through 11 summarize the overall results of Experiment II. These results were calculated for the period starting at 4.0 minutes into the flight and ending 14.5 minutes into the flight. Two reasons motivated this choice of time period: 1) prior to 4.0 minutes, all flights were equivalent except for the availability of autopilot, 2) after 14.5 minutes, the abnormalities and emergencies inherently differed because the abnormalities were resolved (i.e., "runway open") while the emergencies were not.

Average depth of planning ($\bar{D}$) was significantly affected by scenario as shown in Table 8 ($F_{4,60} = 4.22$, $p < .005$). Multiple comparisons indicated that the N scenario differed significantly from the other four scenarios which were similar in terms of $\bar{D}$. The results for $p(D \geq 8)$ were similar to those for $\bar{D}$ ($F_{4,60} = 5.18$, $p < .005$).

Average workload ($\bar{W}$) was significantly affected by scenario ($F_{4,60} = 9.42$, $p < .001$) with the A_1 and A_2 scenarios producing lower $\bar{W}$ than the N, E_1, and E_2 scenarios (Table 8). σ_C and σ_A were also significantly affected by scenario ($F_{4,60} = 6.15$, $p < .001$ and $F_{4,60} = 8.35$, $p < .001$, respectively) with the E_1 scenario producing larger values of σ_C and σ_A than the other four scenarios (Table 8).

While $\bar{D}$ and $p(D \geq 8)$ did not significantly differ for the three flight phases, $\bar{W}$, σ_C, and σ_A were significantly affected ($F_{2,60} = 9.29$, $p < .001$; $F_{2,60} = 13.17$, $p < .001$; and

Table 8: Results vs. scenario for Experiment II

SCENARIO	$\bar{D}$	p(D≧8)	$\bar{W}$	σ_C	σ_A
N	4.82	.059	4.34	0.75	1.95
A_1	6.54	.378	3.83	0.73	1.66
A_2	6.08	.323	3.83	0.87	2.19
E_1	5.79	.325	5.85	1.45	4.39
E_2	6.64	.470	5.12	0.72	2.23

Table 9: Results vs. flight phase for Experiment II

FLIGHT PHASE	$\bar{W}$	σ_C	σ_A
Initial App.	3.95	0.76	3.21
Final App.	4.53	0.64	1.76
Landing	5.30	1.30	2.49

Table 10: Results vs. automation for Experiment II

AUTOMATION	$\bar{W}$	σ_A
Manual	4.87	2.87
Autopilot	4.31	2.10

Table 11: Depth of planning vs. scenario and automation for Experiment II

SCENARIO	AUTOMATION	$\bar{D}$	p(D≧8)
$\bar{A}$	Manual	6.91	.478
$\bar{E}$	Manual	5.79	.273
$\bar{A}$	Autopilot	5.74	.198
$\bar{E}$	Autopilot	6.67	.522

$F_{2,60} = 6.19$, $p < .005$; respectively). More specifically, Landing produced significantly higher $\bar{W}$ and σ_C than the other two phases. However, σ_A was higher for Initial Approach than for the other two phases. These results are shown in Table 9.

The main effect of level of automation was only significant for $\bar{W}$ and σ_A ($F_{1,60} = 4.51$, $p < .05$ and $F_{1,60} = 5.28$, $p < .05$, respectively). As shown in Table 10, manual control resulted in higher $\bar{W}$ and σ_A. The interaction of scenarios and level of automation significantly affected $p(D \geq 8)$ and, if the N scenario was omitted from the analysis, $\bar{D}$ was similarly affected ($F_{4,60} = 4.54$, $p < .005$ and $F_{3,45} = 2.99$, $p < .05$, respectively). Table 11 illustrates the nature of this interaction. The basic result is that abnormal scenarios with manual control and emergency scenarios with autopilot were similar in terms of producing larger values of both $\bar{D}$ and $p(D \geq 8)$ than resulted with abnormal scenarios with autopilot and emergency scenarios with manual control. A possible explanation of this interesting interaction will be discussed in Section 4.1.

3.2.2 Relationships Among Measures

The results of the correlation analyses for Experiment I that were presented in Section 3.1.2 motivated a detailed study of the relationships among measures using the data from Experiment II. The correlations of $\bar{D}$ with $\bar{W}$, σ_C, and σ_A were determined on the basis of 90 measurements (5 scenarios, 3 flight phases, 2 levels of automation, and 3 subjects). The only significant ($p<.05$) correlation was between $\bar{D}$ and $\bar{W}$ ($r = .377$).

The correlations of $\bar{W}$ with σ_C and σ_A, σ_C with σ_A, Δ_C with σ_C, and Δ_A with σ_A were determined on the basis of 150 measurements (i.e., for 5 flight phases rather than 3). All of these correlations were significant; $r = .562$ for $\bar{W}$ and σ_C, $r = .489$ for $\bar{W}$ and σ_A, $r = .820$ for σ_C and σ_A, $r = .977$ for Δ_C and σ_C, and $r = .943$ for Δ_A and σ_A. Clearly, the four performance measures σ_C, σ_A, Δ_C, and Δ_A are highly redundant.

The redundancy was also true of localizer and glideslope deviations which were significantly correlated with σ_A (r=.861).

3.2.3 Time Histories of Depth of Planning

Figures 8 through 14 present time histories of depth of planning averaged across subjects, levels of automation, and similar scenarios (i.e., each point is an average of six measurements for normal scenarios, twelve measurements for abnormal and emergency scenarios, and three measurements for the multiple event scenario). Figures 8, 9, and 10 are the time histories for the flight phases Initial Approach, Final Approach, and Landing, respectively. Perhaps the most distinguishing feature of this time histories is the consistent way in which all four types of scenarios have similar values of $\bar{D}$ for the early and later portions of the flight, but during the middle portion of the flight, abnormal, emergency, and multiple event scenarios have consistently higher values of $\bar{D}$. This provides further evidence for the dichotomy introduced in Section 3.1.3, namely, event-driven and time-driven planning. Specifically, the abnormal and emergency "events" cause increased planning until time-driven planning predominates as the flight phase of interest becomes closer. This effect is greatest for the multiple event scenario.

While one might expect the abnormalities and emergencies to have different effects on depth of planning, the results presented in Section 3.2.1 do not support this hypothesis and there is no evidence for such a differential effect in Figures 8, 9, and 10 with the possible exception of the multiple event scenario. However, the time histories of depth of planning for the subtasks "Weather minima" and "Runway condition", shown in Figures 11 and 12, do exhibit this effect. This difference is clearly due to the fact that the abnormalities, which also occurred in the multiple event scenario, involved inclement weather while the other scenarios did not. Apparently, the measure of depth of planning for the

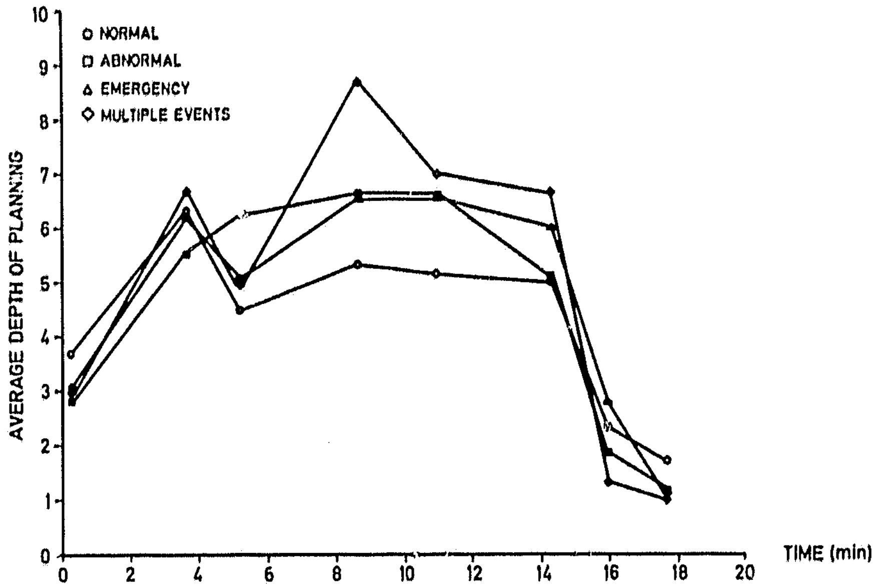

Figure 8: Average depth of planning for Initial Approach

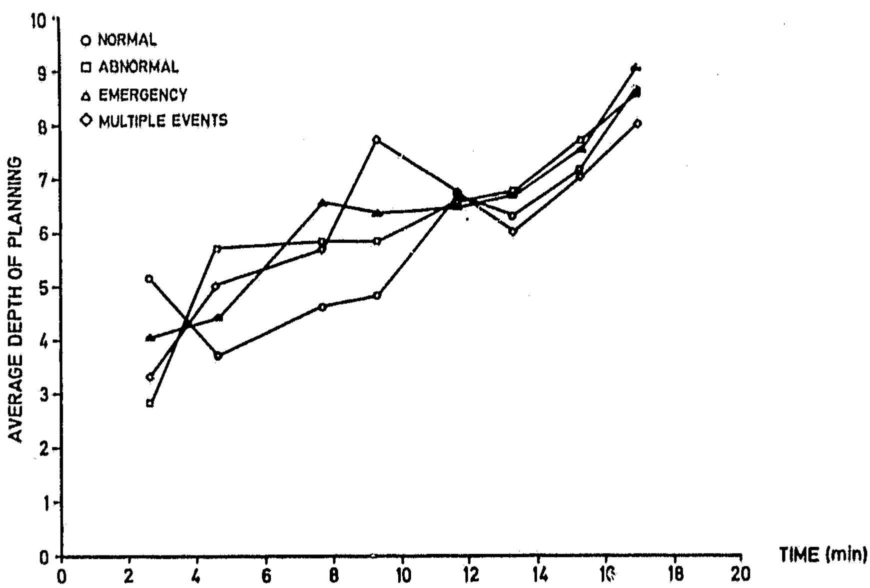

Figure 9: Average depth of planning for Final Approach

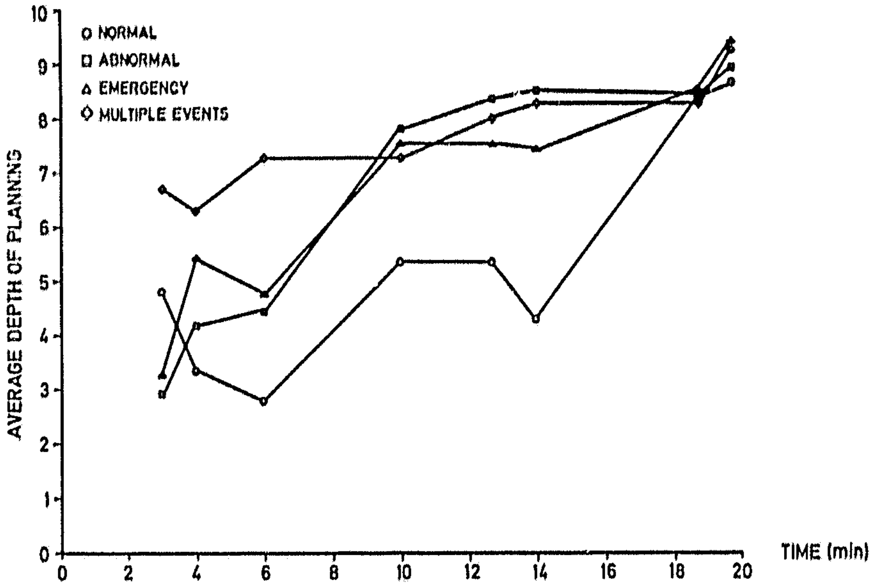

Figure 10: Average depth of planning for Landing

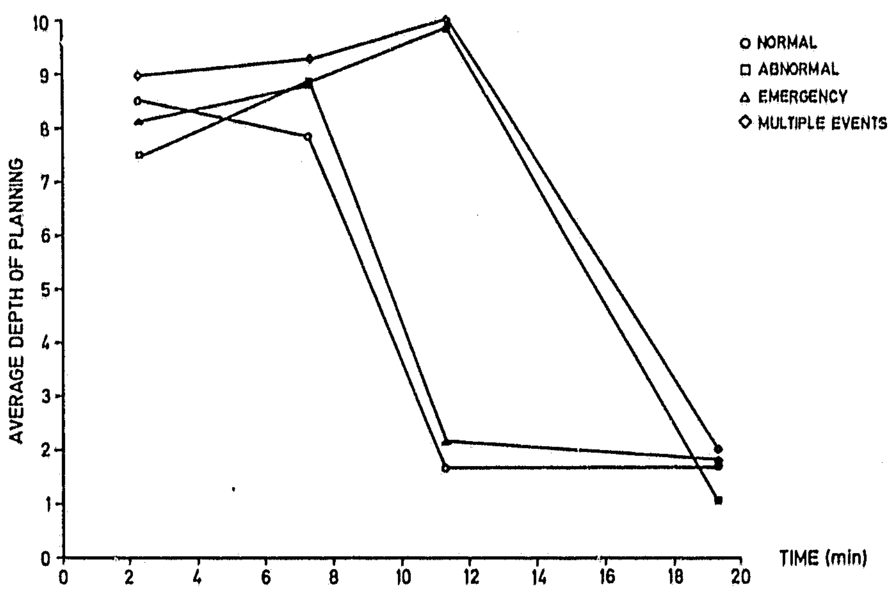

Figure 11: Average depth of planning for Weather Minima

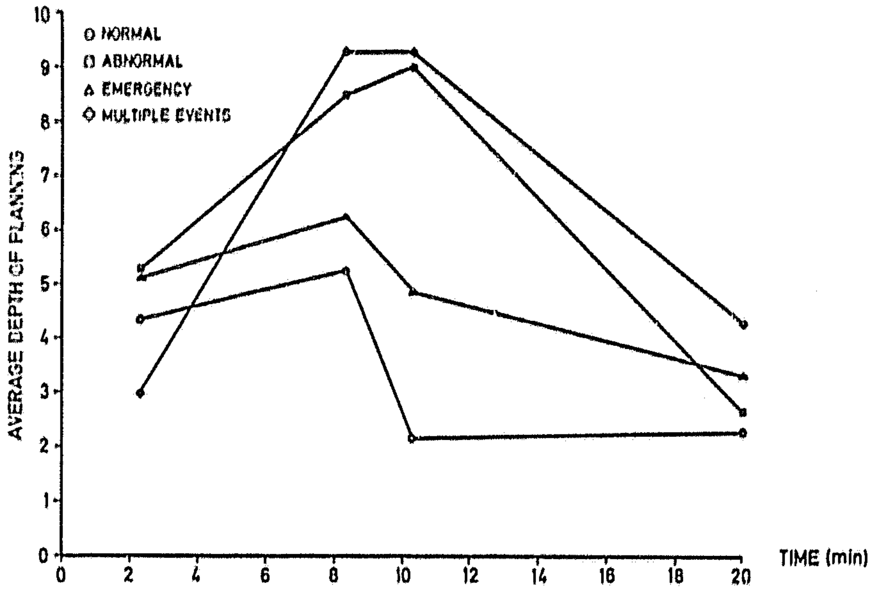

Figure 12: Average depth of planning for Runway Condition

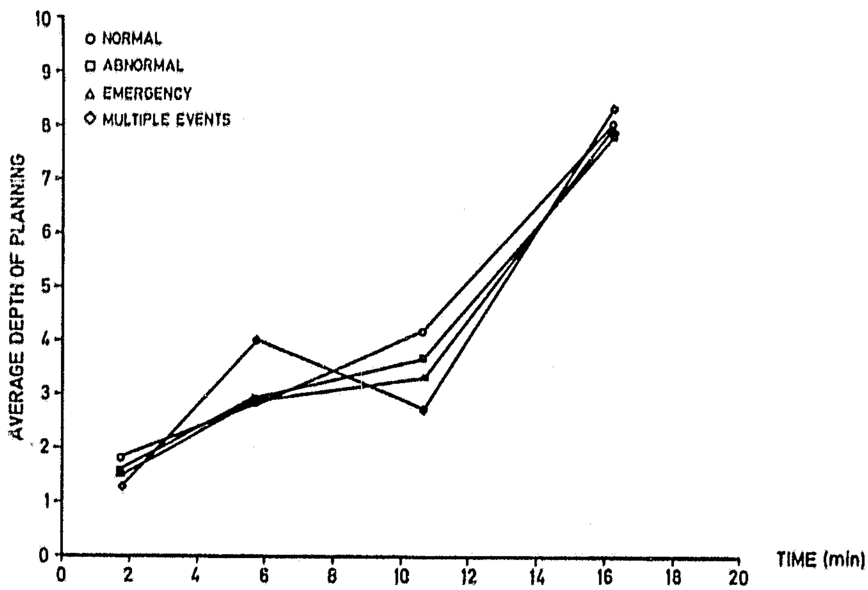

Figure 13: Average depth of planning for Localizer Intercept

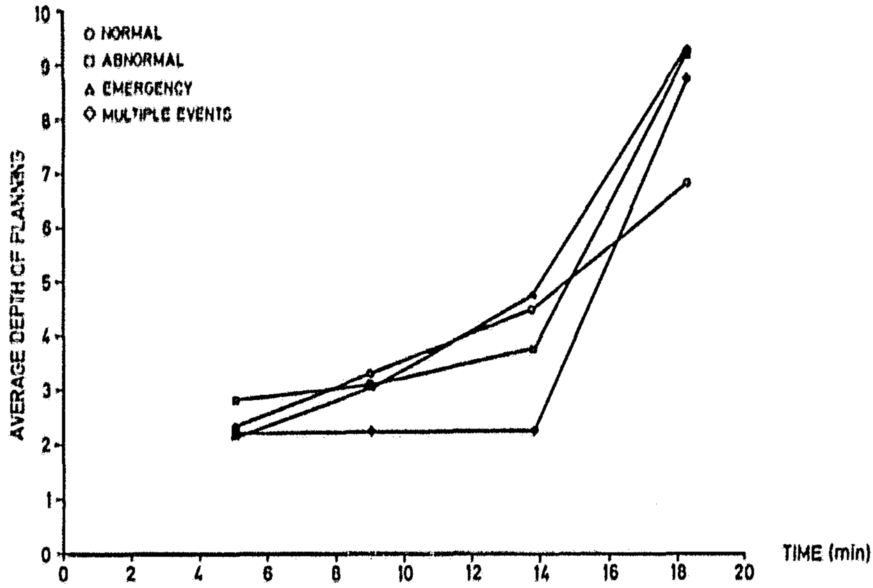

Figure 14: Average depth of planning for Glideslope Intercept

overall flight phases is not sensitive enough to discriminate among types of event, at least when averaging across subjects, levels of automation, and similar scenarios.

Figures 13 and 14 show the time histories of depth of planning for the subtasks "Localizer intercept" and "Glideslope intercept". The planning reflected in these time histories is clearly time-driven and not affected by differences in scenarios. These results serve to point out that planning with respect to some subtasks may be unaffected by abnormal or emergency events; these subtasks may be viewed as purely time-driven.

4. Discussion and Conclusions

4.1 Summary of Important Results

While a variety of interesting empirical results have emerged from the studies reported here, three results deserve special emphasis in this section. The first result of particular interest is the identification of the dichotomy between event-driven and time-driven planning. It appears that event-driven planning can be described as updating a script or creating a new script while time-driven planning involves monitoring the execution of a script. The time histories of depth of planning presented in Sections 3.1.3 and 3.2.3 support this description in that the abnormalities and emergencies mainly affected the event-driven portions of the time histories. The time-driven portions were not differently affected by the scenarios because the plan had already been updated to reflect the abnormalities and emergencies.

The second result of interest is the way in which depth of planning was affected by the interaction of scenario and level of automation in Experiment II. Why does the availability of autopilot result in decreased planning during abnormal scenarios and increased planning during emergency scenarios? While one might postulate this effect to be a by-product of the lower workload during the abnormal scenarios, the low correlation between depth of planning and workload does not support this hypothesis.

This unusual effect of autopilot on depth of planning can perhaps be explained by the nature of the abnormal and emergency scenarios. The abnormalities involved changes in the environment (i.e., runway closure due to snow or fog) while the emergencies involved changes within the aircraft (i.e., engine failure or loss of hydraulic pressure). Despite these differences, the average depths of planning were remarkably similar, averaging 6.31 and 6 22 for abnormal and emergency scenarios, respectively. Yet, the autopilot did have a differential effect on planning.

One can conjecture that the key to explaining this somewhat counterintuitive result is the effect of the autopilot on the types of event. The autopilot controls the aircraft but not the environment. Therefore, the autopilot can help to compensate for events within the aircraft but cannot directly affect events in the environment. Thus, when an engine failure or loss of hydraulic pressure occurs, the autopilot can help to compensate and thereby free the pilot to plan the course of actions necessary to deal with the failures. As a result, the availability of the autopilot during such emergencies results in increased planning.

In contrast, abnormal situations such as the runway closures used in these experiments result in the pilot's main task being holding and waiting. While some planning might be associated with the possibility of diverting to an alternate airport, this possiblity was not heavily stressed in these experiments. Thus, the planning that is necessary mainly involves the "holding" task. However, if the autopilot is available, it performs much of this task and, as a result, the pilot's planning decreases.

To summarize the conjecture offered here, during emergencies the autopilot frees the pilot to devote more time to planning; during abnormalities the autopilot assumes a significant portion of the task and lessens the need for planning. While this notion is somewhat speculative and needs further investigation, it does serve to emphasize the possible subtle effects of automation.

The third result of particular interest is the low correlation between depth of planning and workload or flight performance. While the fair to high correlation between workload and control activity agrees with one's intuition, the fact that an increased need for planning did not greatly affect perceived workload is rather counterintuitive. It is quite possible that the pilots perceived workload in terms of having to do something and, since planning is an internal activity, they did not associate planning with work or effort. Alternatively, this result can be viewed as evidence that workload is a multidimensional concept that cannot be reduced to a scalar metric. From this perspective, the human information processing associated with the tracking task of flight control should be viewed as quite different from the information processing associated with planning.

4.2 Implications of Results

The results presented in this report have both methodological and theoretical implications. From a methodological point of view, the inflight questionnaire techniques developed for this research, as well as the pre-experiment and post-experiment questionnaires utilized, provided a variety of insights into human planning behavior that would not have been gained if only traditional performance and workload measures had been assessed. Indeed, the results of the correlation analyses reported here indicate that such traditional measures relate only weakly, if at all, to planning behavior.

While the assessment of depth of planning does suffer from being only an introspective report, this limitation is by no means as severe as encountered with verbal protocols because depth is measured quantitatively and can therefore be subjected to various statistical tests that account for experimental error. Of course, this increased rigor comes at a price of losing some of the richness of verbal protocols. One possible avenue of future research would be to utilize a mixture of the two methods.

Considering theoretical implications, perhaps the most important aspects of this research relate to the dynamic, uncertain aircraft domain which was studied. Planning was driven by the both the onslaught of time and the occurrence of unanticipated events. In this respect, the aircraft domain is quite different from the restaurants [Schank and Abelson, 1977] and shopping trips [Hayes-Roth and Hayes-Roth, 1979] studied by other investigators of planning.

As a result of this difference, the aircraft domain provided evidence for both hierarchical, time-driven following of scripts and opportunistic, event-driven planning. Thus, both extremes of hierarchical and heterarchical planning are useful for describing human planning behavior in complex, dynamic environments. Based on this conclusion, the next phase of this research should focus on integrating the formalized models of planning proposed by the researchers discussed in the Introduction.

4.3 Conclusions

This report has presented a methodology for studying planning behavior of aircraft pilots and discussed an application of this methodology within two very realistic flight experiments. Beyond showing that the methodology yields consistent results, these experiments also produced new concepts in terms of the dichotomy between event-driven and time-driven planning, the subtle effects of automation on planning, and the relationship of planning to workload and flight performance.

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A P P E N D I C E S

A. HFB-320 Simulator

A.1 General Description

The simulated aircraft type used in this study was a twin engined HFB-320 Hansa Executive Jet manufactured by Messerschmitt-Bölkow-Blohm, Hamburger Flugzeugbau. An original mockup of the manufacturer including the primary flight controls and consoles was fitted with a typical instrument arrangement for category II operation (Decision hight 100 ft, Runway Visual Range 1,300 ft). Although the HFB-320 is flown with a two-man crew, it was decided to omit the co-pilots flight instruments in this research flight simulator in order to allow a greater flexibility in various investigations.

The flight simulator allows full maneuverability and is designed to have a high quality of realism during approaches using a simulated instrument landing system (ILS). It is fixed base, provides simulation of turbulence weather conditions and has no visual simulation system of the outside view. An autopilot and flight director system is provided to permit automatic control of the aircraft in its three axes.

Additionally, the simulator has a feature known as Control Wheel Steering (CWS) or Force Wheel Steering to allow the pilot to enter the automatic control loops in all modes of autopilot operation. This is done by adding force sensors to the pilot's control wheel plus installing a force wheel steering coupler to the autopilot system.

The signals of the primary flight controls (elevator, aileron, rudder) and the secondary flight controls (i.e., all primary control surface trim systems, wing flaps, leading edge slats, speed brakes) are inputs to the mathematical model of the aircraft stored in an EAI 640 computer. This is a small digital computer having a capacity of 16 k of 16 bit words. The real-time simulation program is updated every 40 ms [Holzhausen and Kühne, 1974].

An interface consisting of three 19'' cabinets serves as a signal processor between the computer and the cockpit. The horizontal situation of the aircraft is computed within a range of 65 km x 65 km. This area should be seen as a digital stored "map" including a true-map grid system. The resolution is 1 m $\hat{=}$ 1 bit. The localizer of the software-installed instrument landing system is placed in the origin of the coordinates. Approaching this ILS, the localizer course is 250° and the inclination angle of the corresponding glideslope is 3.1°. The ILS-markers OM (Outer Marker) and MM (Middle Marker) are part of the digital "map", too.

There is a 2-pen x-y plotter recording both lateral and vertical flight path which provides on-line monitoring plus hardcopy availability of the flight mission to the experimenters. The horizontal coverage of the plotter is 20 km x 32 km. The vertical area corresponds to the range of typical radio altimeters (2,500 ft). Figure 1 is a plot of a vectored ILS-approach

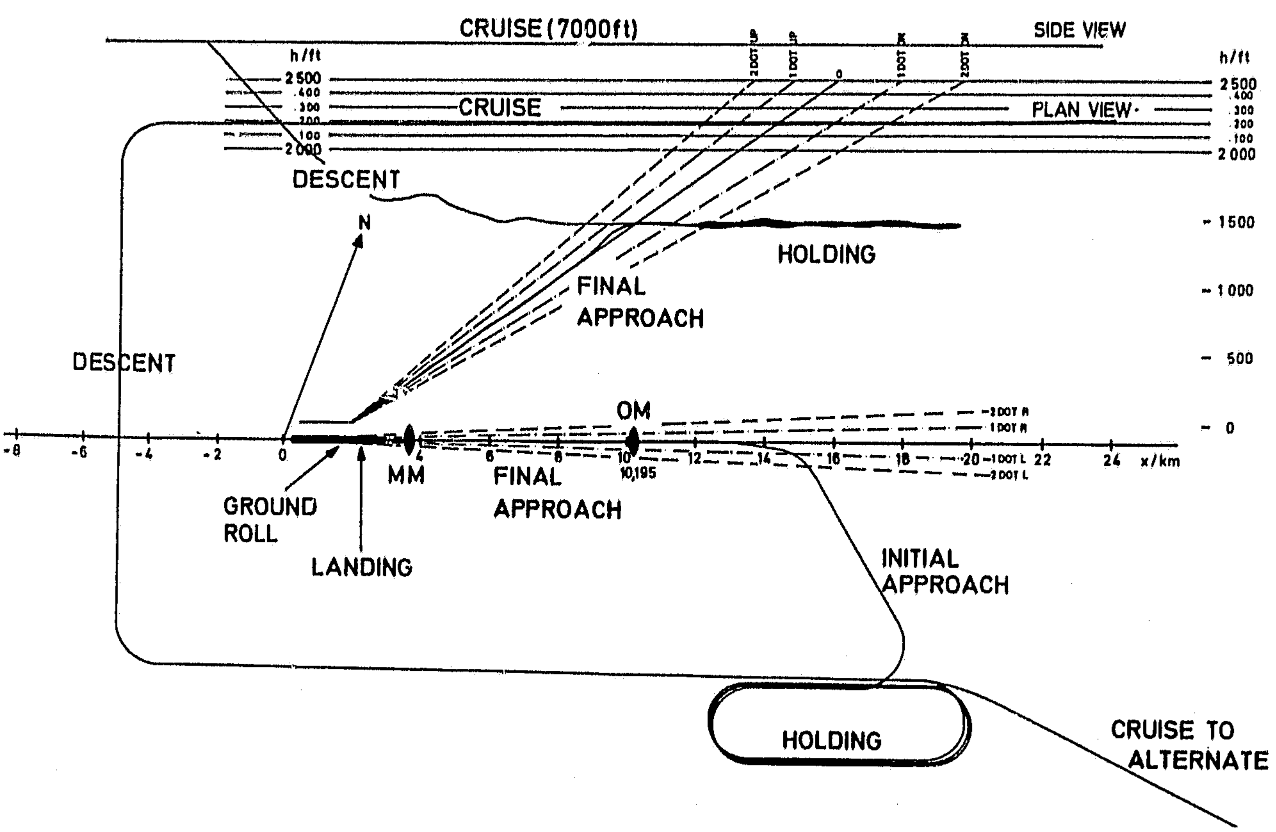

Figure 1: Flight situation map

flight mission with a 310° localizer inbound course (plan view of the INITIAL APPROACH), glideslope capture in the vicinity of the outer marker (OM), and the final approach at the flight base line. The upper curve (side view) is the reading of the radio altimeter descending from 7,000 ft (out of range) to 1,500 ft (HOLDING ALTITUDE), and shows finally the tracking of the glideslope.

A.2 Capabilities and Limitations

The main article of equipment in the flight simulator is a real Collins AP-104/FD 109 H autopilot and flight director system. This system consists of several black boxes housed in the interface cabinets, three autopilot servos to operate the primary flight controls of the simulator, the trim indicators, and finally the controls and displays as part of the pilot's equipment in the cockpit [Collins, 1968].

The displays are the flight director indicator (FDI) and the course indicator (CI). They are installed in the center field of view at the pilots side of the instrument panel (Figure 2). The flight director indicator (FDI) provides a quasi-3-dimensional display of aircraft attitude and steering commands. Pitch and roll attitudes are displayed by the relationship of a fixed aircraft symbol to the movable attitude tape. Both, vertical and lateral steering information are derived from the resident flight computer of the system. To fly on the proper flight path, the pilot's input to the flight controls has to align the command bars (V-bars) to the fixed aircraft symbol positioned in the center of the instrument. The FDI also includes a runway symbol (corresponding to localizer deviation and radio altitude), a glideslope indicator, a rate-of-turn indicator, and the annunciator lights for go-around and the minimum decision altitude (MDA).

A fixed airplane symbol on the course indicator (CI) shows airplane position and heading with respect to the azimuth card, lateral deviation bar, and selected heading. The lateral

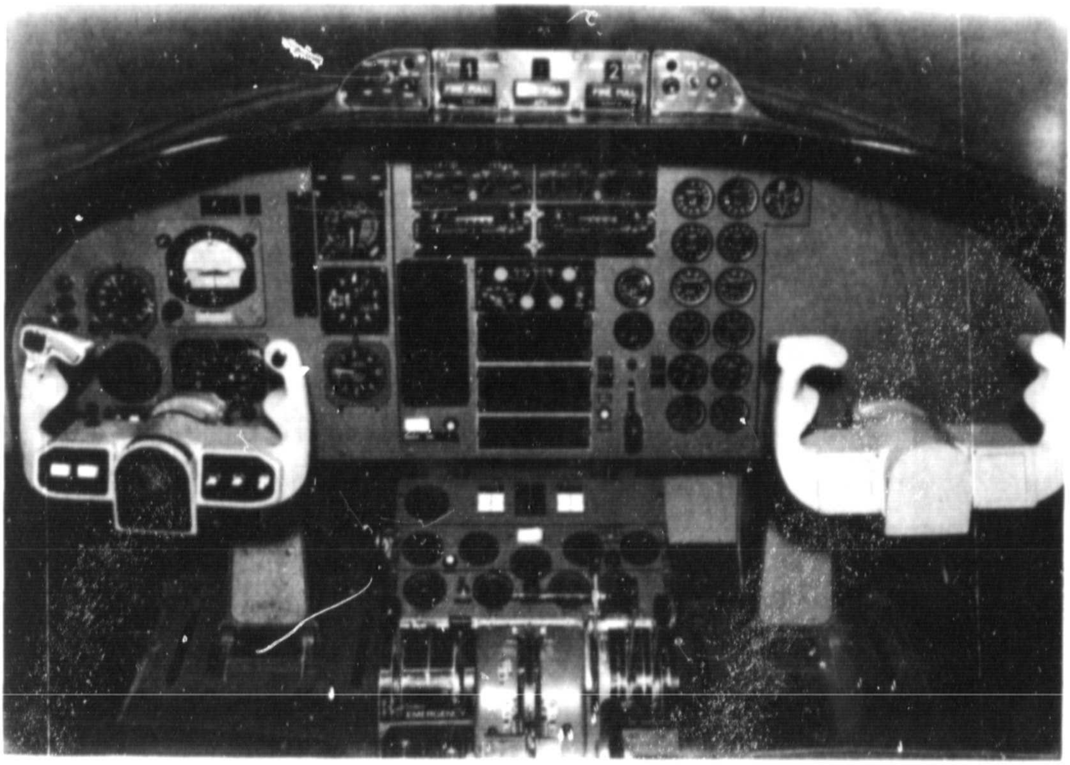

Figure 2: Instrument panel, flight controls, and pedestal

deviation bar represents the center line of the selected VOR-course (Very high frequency Omnidirectional Range) or localizer course. However, there is no simulation of VOR or NDB (Non Directional Beacon) included in the HFB-320 simulator. Thus, the localizer is the one and only instrument navigation facility in this configuration. Aircraft position above or below the glideslope is shown by the position of the glideslope pointer of the CI in relation to the center line of a glideslope scale. The pointer and scale repeat the glideslope indication given by the flight director indicator.

There are a couple of autopilot/flight director system warning flags in the FDI and CI to indicate a malfunction of the associated subsystem. Limited system operation is possible with only some of the flags in view. If, for example, HEADING and GYRO flags are in view (indicating a failure of compass and vertical gyro system), the localizer information will be still correct and usable.

To supply mode and command functions for the autopilot and flight director system there are an autopilot controller and a mode selector installed in the pedestal of the cockpit. The autopilot controller provides turn and pitch command knobs for the manual control mode of the autopilot. An engage lever engages or disengages the autopilot servo clutches to or from the control surfaces. Additionally, there is an autopilot manual switch to couple or uncouple the flight director to the autopilot. The mode selector enables the pilot to select various lateral or vertical (or any combination) modes of the flight director. Table 1 is a listing of the modes of the flight director either coupled or uncoupled to the autopilot.

Table 1: Flight control system modes

Lateral Modes		Vertical Modes	
ROLL	maintains roll attitude	PITCH	maintains pitch attitude
HEADING	maintains selected heading	IAS	maintains indicated airspeed
VOR/LOC	tracks VOR-radial or localizer	VS	maintains vertical speed
APPROACH I	tracks ILS Cat. I	ALT	maintains altitude present at the time of engagement
APPROACH II	tracks ILS Cat. II		

Consequently, there are four basic modes to fly the aircraft:

I. Manual Mode

The autopilot is disengaged and the flight director is turned off. The pilot has to use the primary flight controls.

II. FD-Manual Mode

The autopilot is disengaged and the flight director is active. The pilot uses the primary flight controls to follow the command display.

III. AP-Manual Mode

The autopilot is engaged and the flight director is uncoupled from the autopilot. The pilot has to use the turn- and pitch-command knobs to control the aircraft. Selecting Control Wheel Steering (CWS) is possible, too.

IV. Automatic Mode

The autopilot is engaged and the flight director is coupled to the autopilot. The pilot monitors operation of the flight control system. Selecting CWS is possible.

Actually, in these experiments only the modes II and IV (without using CWS) were flown by the pilots. Permitting the pilot to monitor flight director and autopilot status, there is an autopilot annunciator panel located on the right side of the flight director indicator. Also, 3 trim indicators (rudder, aileron, elevator) provide visual indication of autopilot force applied to the respective control surfaces.

The HFB-320 simulator includes a full set of conventional flight and engine instruments as well as marker lamps, annunciator warning panel, radio call plate, and audio selector panel [MBB-UHFB, 1970]. The conventional flight instruments are:

a) Turn and Bank Indicator

b) Airspeed Indicator

c) Radio Magnetic Indicator (not used)

d) Radio Altimeter

e) Barometric Altimeter

f) Vertical Speed Indicator

The following engine instruments are installed (one set for each engine):

a) Engine speed (RPM)

b) Engine pressure ratio (EPR)

c) Exhaust gas temperature (EGT)

d) Oil temperature

e) Oil pressure

f) Fuel flow

The landing gear control system located on the instrument panel incorporates a control switch for normal gear extension or retraction and an indicator to monitor the position and condition of the nose and main landing gear.

A flap position indicator is placed above the landing gear position indicator. The flaps are operated from the flap control lever in the pedestal. Flap lever detents provide 0°, 20°, 30°, and 50° flap positions. Elevator trim wheel, aileron and rudder trim switches plus trim position indicator, speed brake switch, outside air temperature, and the throttles are housed in the pedestal of the cockpit.

The pilot's control wheel is fitted with an autopilot disengage button, elevator electrical trim switch, go-around mode switch, CWS mode switches for roll- and pitch-axis (not activated in this study), and an ATS (Automatic Throttle System) mode switch. Selecting ATS maintains the indicated airspeed present at the time of engagement. This is done by increasing or decreasing engine speed via computer control.

Most of the controls in the overhead panel, the overhead and bulkhead circuit breaker panel, and the shroud panel are missing. However, starting switches for the engines, cockpit lighting switches and ventilator switches are available.

The HFB-320 simulator is equipped with a Control-Feel Simulation System and a Sound Simulation System. Generating the artificial control feel is done by using two torque motors in the pitch axis and one torque motor in the roll axis. All of the three torque motors are powered from their respective power amplifiers housing in an interface cabinet.

The Sound Simulator generates electronically synthesized aircraft sounds to provide realistic audible sounds that are normally heard at the flight deck of an aircraft. Aircraft sounds presented are [Gärtner and Hillmann, 1975]:

a) Engine N° I - sound ⎤ (impeller and turbine whine,
b) Engine N° II- sound ⎦ inlet ram air, and exhaust air)

c) Aerodynamic airspeed-sound

d) Landing gear extension - and retraction-sound

e) Rolling wheels-sound

An intercom audio selector panel at the pilot's side panel of the cockpit completes the equipment of the simulator flight deck. The intercom provides communication between the pilot and the experimenters.

B. Flight Scenarios

B.1 Scenarios for Experiment I

The flight missions prepared for these studies should be divided into three different flight situations:

a) Normal situation (N)

b) Abnormal situation (A)

c) Emergency situation (E)

Initial conditions for every flight mission were always the same and are given in the following: (Aircraft position reference datum is the localizer transmitter.)

x-position:	+ 24,000 m
y-position:	+ 9,500 m
Altitude:	7,000 ft
Indicated airspeed:	140 kts
Vertical speed:	0 ft/min
Heading	250°
Flap setting:	20°
Elevator trim wheel setting:	6 divisions nose up
Power setting:	83 % RPM (both engines)
Landing gear:	UP (retracted)
Turbulence conditions:	moderate vertical gusts (0.3 m/s)
Automatic Throttle System:	ON (engaged)
Flight Director Mode:	HEADING HOLD, ALTITUDE HOLD

The pilots were told to use the ATS in all flight phases except Landing and Ground Roll. They were asked never to change the flap setting and never to use the speed brakes.

B.1.1 The Normal Scenario

The normal situation (N scenario) is the basic flight scenario and was designed to have seven flight phases. Table 2 is a complete listing of the ATC instructions (Air Traffic Controller) for this normal scenario given by one of the experimenters. A time schedule is included and the associated flight phases are labeled.

Some instructions do not include the exact time of report. Due to the various rates of descent executed by the pilots, only an estimated time of report is possible. There is no occurrence of an abnormal or unexpected event causing the pilot to initiate an abnormal or emergency procedure. The flight director remains active during the total flight mission. However, the autopilot is disengaged and the pilot manually follows the command display.

Table 2: ATC instructions for N scenario

TIME min sec	FLIGHT PHASE	ATC INSTRUCTION	PILOT'S RESPONSE
00 : 00	Cruise	HFB Experiment inception.	Affirmative.
06 : 15	Cruise	HFB is cleared for crosswind leg, make a left turn HDG 160.	Left turn 160 for crosswind.
07 : 15	Descent	HFB is cleared to 1,500 ft, report reaching 1,500.	Cleared to 1,500, will report reaching.
08 : 15		HFB, Cologne weather: QNH as given, wind calm, visibility 10 +.	Thanks for the weather.
09 : 15	Descent	HFB is cleared for downwind leg, make a left turn HDG 070.	Left turn 070 for downwind.
11 : 30	Descent	(estimated time of report only)	HFB reaching 1,500.
15 : 15	Holding	HFB enter holding pattern, make a right turn HDG 250.	Right turn 250 for holding.
17 : 15	Holding	HFB make a right turn HDG 070.	Right turn 070.
19 : 15	Holding	HFB make a right turn HDG 250.	Right turn 250.
21 : 15	Holding	HFB make a right turn HDG 070.	Right turn 070.
23 : 15	Holding	HFB make a right turn HDG 250.	Right turn 250.
25 : 15	Holding	HFB make a right turn HDG 070.	Right turn 070.
26 : 45	Initial Approach	HFB is cleared for base leg, make a left turn HDG 310.	Left turn 310 for base.
27 : 45	Initial Approach	HFB is cleared to ILS 25, report position OM.	Cleared to ILS 25, will report OM.
29 : 45	Final Approach	(estimated time of report only).	HFB position OM.
		cleared to land, check gear, report touch down.	Cleared to land, three greens, will report touch down.
	Landing	-	-
31 : 30	Ground Roll	(estimated time of report only).	HFB touch down.

B.1.2 Changes for the Abnormal Scenarios

The major difference between the basic scenario and the A scenarios (abnormal scenario) is the occurrence of poor weather conditions given via ATC instructions. This causes the pilot to consider procedural changes including the possibility of an additional flight phase, i.e., "cruise to alternate".

In the A_1 scenario, the pilot receives at 04:45 the information that runway 25 is closed due to heavy snowfall. He is informed that snow removal is in progress and advised to stand by for further information. At 06:15, the pilot is instructed to enter a holding pattern before descending. After getting cleared for crosswind leg and leaving 7,000 ft for 1,500 ft, he receives the information that the runway is clear and wet. This information forces the pilot to cancel the possibility of a "cruise to alternate" and to continue his approach. A complete listing of the ATC instructions for the A_1 scenario is given in Table 3.

The ATC instructions for the A_2 scenario given in Table 4 include a warning message at 08:15 concerned with an anticipated snowfall, followed by detailed weather information and the resulting instructions for procedural changes.

Both of the abnormal scenarios A_1 and A_2 were exclusively flown with an active flight director during the total flight and the autopilot engaged until decision height.

B.1.3 Changes for the Emergency Scenarios

The emergency flight scenarios were characterized by an unexpected loss of engine N° II thrust. This is done by activating an engine shut-down switch located at the experimenters' desk. The engine N° II shut-down is initiated at 14:45 in case of E_1 scenario. Because of the single engine failure, the holdings were completely cancelled and the pilot is cleared to continue his approach immediately. Cancellation of the

Table 3: ATC instructions for A_1 scenario

TIME min sec	FLIGHT PHASE	ATC INSTRUCTION	PILOT'S RESPONSE
00 : 00	Cruise	HFB Experiment inception.	Affirmative.
04 : 45	Cruise	HFB, Cologne weather is temporarily below minima, runway 25 is closed due to heavy snowfall, snow removal in progress for 10 minutes, standby for further information.	Affirmative, request holding pattern.
06 : 15	Holding	HFB enter holding pattern, make a left turn HDG 070.	Left turn 070 for holding.
08 : 15	Holding	HFB make a left turn HDG 250.	Left turn 250.
10 : 15	Holding	HFB make a left turn HDG 070.	Left turn 070.
12 : 15	Holding	HFB make a left turn HDG 250.	Left turn 250.
14 : 15	Holding	HFB make a left turn HDG 070.	Left turn 070.
16 : 15	Holding	HFB make a left turn HDG 250.	Left turn 250.
18 : 15		HFB is cleared for crosswind leg, make a left turn HDG 160.	Left turn 160 for crosswind.
19 : 15	Descent	HFB is cleared to 1,500, report reaching 1,500. Runway 25 is clear and wet. Cologne weather: QNH as given, wind calm, visibility 10 +.	Cleared to 1,500, will report reaching. Thanks for the weather.
21 : 45	Descent	HFB is cleared for downwind leg, make a left turn HDG 070.	Left turn 070 for downwind.
23 : 30	Descent	(estimated time of report only).	HFB reaching 1,500.
26 : 45	Initial Approach	HFB is cleared for base leg, make a left turn HDG 310.	Left turn 310 for base.
27 : 45	Initial Approach	HFB is cleared to ILS 25, report position OM.	Cleared to ILS 25, will report OM.
29 : 45	Final Approach	(estimated time of report only).	HFB position OM.
		Cleared to land, check gear, report touch down.	Cleared to land, three greens, will report touch down.
	Landing	-	-
31 : 30	Ground Roll	(estimated time of report only).	HFB touch down.

Table 4: ATC instructions for A_2 scenario

TIME min sec	FLIGHT PHASE	ATC INSTRUCTION	PILOT'S RESPONSE
00 : 00	Cruise	HFB Experiment inception.	Affirmative.
06 : 15	Cruise	HFB is cleared for crosswind leg, make a left turn HDG 160.	Left turn 160 for crosswind.
07 : 15	Descent	HFB is cleared to 1,500 ft, report reaching 1,500.	Cleared to 1,500, will report reaching.
08 : 15	Descent	HFB, we expect snowfall, stand by for further information.	Affirmative.
09 : 45	Descent	HFB is cleared for downwind leg, make a left turn HDG 070.	Left turn 070 for downwind.
11 : 30	Descent	(estimated time of report only).	HFB reaching 1,500.
13 : 45		HFB, Cologne weather is fairly CAT I, runway 25 is closed due to heavy snowfall, snow removal in progress for 10 minutes, standby for further information.	Affirmative, request holding pattern.
15 : 15	Holding	HFB enter holding pattern, make a right turn HDG 250.	Right turn 250 for holding.
17 : 15	Holding	HFB make a right turn HDG 070. We expect runway to be clear in 10 minutes.	Affirmative, right turn 070.
19 : 15	Holding	HFB make a right turn HDG 250.	Right turn 250.
21 : 15	Holding	HFB make a right turn HDG 070.	Right turn 070.
23 : 15	Holding	HFB make a right turn HDG 250.	Right turn 250.
25 : 15	Holding	HFB make a right turn HDG 070, runway 25 is clear and wet, Cologne weather: QNH as given, wind calm, visibility 10 +.	Affirmative, right turn 070, thanks for the weather.
26 : 45	Initial Approach	HFB is cleared for base leg, make a left turn HDG 310.	Left turn 310 for base.
27 : 45	Initial Approach	HFB is cleared to ILS 25, report position OM.	Cleared to ILS 25, will report OM.
29 : 45	Final Approach	(estimated time of report only).	HFB position OM.
		Cleared to land, check gear, report touch down.	Cleared to land, three greens, will report touch down.
	Landing	-	-
31 : 30	Ground Roll	(estimated time of report only).	HFB touch down.

holdings reduces the time duration of the E_1 scenario to about 20 minutes.

At the E_2 scenario, the engine failure was initiated shortly after the pilot had reported his outer marker position, i.e., approximately at 30:00. Disregarding the engine failure, the E_2 scenario is identical to the N scenario. The pilot was instructed to continue his approach as possible and to report touch down. Manual flight control with an operating flight director was used to execute the emergency flight scenarios. After detecting the engine failure, the pilots were not expected to execute the complete engine shut-down procedure specified by the aircraft manufacturer. Instead, they were told to compensate the loss of thrust by using the respective trim switches for rudder and aileron. To improve thrust control of the operative engine, they were allowed to disengage the automatic throttle system if desired.

The time schedules for the emergency scenarios E_1 and E_2 correspond to that of the N scenario with the exception of the engine failures as described in this section (see Table 2).

B.2 Scenarios for Experiment II

The flight missions used in the Experiment II include several modifications for the normal, abnormal, and emergency scenarios. The major difference is the absence of the flight phase "Holding" in any type of flight mission. In the following, all the changes will be explained in detail. Time schedules and ATC instructions for normal, emergency, and multi-event scenarios are added. The initial conditions are identical to the ones used in the first experiment. All the various types of scenarios were flown with both the manual and the autopilot mode.

Table 5: ATC instructions for N scenario (Experiment II)

TIME min sec	FLIGHT PHASE	ATC INSTRUCTION	PILOT'S RESPONSE
00 : 00	Cruise	HFB Experiment inception.	Affirmative.
06 : 10	Cruise	HFB is cleared for crosswind leg, make a left turn HDG 160.	Left turn 160 for crosswind.
07 : 10	Descent	HFB is cleared to 1,500 ft, report reaching 1,500.	Cleared to 1,500, will report reaching.
08 : 10		HFB, Cologne weather: QNH as given, wind calm, visibility 10 +.	Thanks for the weather.
09 : 50	Descent	HFB is cleared for downwind leg, make a left turn HDG 070.	Left turn 070 for downwind.
12 : 00	Descent	(estimated time of report only).	HFB reaching 1,500.
15 : 10	Initial Approach	HFB is cleared for base leg, make a left turn HDG 310.	Left turn 310 for base.
15 : 30	Initial Approach	HFB is cleared to ILS 25, report position OM.	Cleared to ILS 25, will report OM.
18 : 00	Final Approach	(estimated time of report only).	HFB position OM.
		Cleared to land, check gear, report touch down.	Cleared to land, three greens, will report touch down.
	Landing	-	-
20 : 30	Ground Roll	(estimated time of report only).	HFB touch down.

B.2.1 The Normal Scenario

This basic flight scenario is again the so-called N scenario. The time schedule with the complete ATC instructions is given in Table 5.

B.2.2 Changes for the Abnormal Scenarios

Comparing the A_1 and A_2 scenarios of Experiment II with Experiment I, there are only slight differences (see also Table 4). Closing the runway due to heavy snowfall is announced at 04:10 for the A_1 scenario. Thus, the possibility of requiring the pilot to enter a holding pattern or to cruise to the alternate airport is presented. The ATC information given at 14:30 opens the runway. This enables the pilot to neglect a holding procedure as well as cruising to the alternate.

The A_2 scenario involves weather conditions temporarily below minima due to dense fog announced at 07:30. This forces the pilot to consider the same possiblities as in the A_1 scenario. An ATC instruction, also announced at 14:30, gives the pilot good visibility to initiate a standard approach.

B.2.3 Changes for the Emergency Scenarios

The first emergency situation (E_1 scenario) is a failure of the N° II engine at 04:10 into the flight. To improve the recognition of the emergency situation for the pilot, all the audible and visible alarm signals similar to those that were used in the real HFB-320 aircraft are supplied to the cockpit. When the pilot had stated his engine failure, the flight was cleared to continue the approach as possible. The time schedule of the E_1 scenario is similar to that of the N scenario (see Table 5). A different type of emergency situation is involved in the E_2 scenario by simulating total loss of hydraulic fluid. The failure is indicated via alarm bell and the flash of the associated warning lamps in the warning panel. Initiating the hydraulic system failure at 07:30 results in making gear lever, emergency gear lever, and emergency hand pump inoperative. Table 6 shows the complete ATC instructions for the E_2 scenario.

The last trial each pilot had to perform in the Experiment II was the ME scenario (Multi-Event). This is a combination of the principal items of the A_1 scenario, E_1 scenario, and the E_2 scenario. Of course, the ME scenario was the most strenuous flight mission to the pilot. To increase the comprehension of what really happened during this flight, a complete listing of the instructions is given in Table 7.

Table 6: ATC instructions for E_2 scenario (Experiment II)

TIME min sec	FLIGHT PHASE	ATC INSTRUCTION	PILOT'S RESPONSE
00 : 00	Cruise	HFB Experiment inception.	Affirmative.
06 : 10	Cruise	HFB is cleared for crosswind leg, make a left turn HDG 160.	Left turn 160 for crosswind.
07 : 10	Descent	HFB is cleared to 1,500 ft, report reaching 1,500.	Cleared to 1,500, will report reaching.
07 : 30		INITIATION OF HYDRAULIC SYSTEM FAILURE.	
07 : 50		(estimated time of report only).	Distress signal (reason, request of foamy runway etc.).
		HFB affirmative, standby for information.	
08 : 10		HFB, Cologne weather: QNH as given, wind calm, visibility 10 +.	Thanks for the weather.
9 : 50	Descent	HFB is cleared for downwind leg, make a left turn HDG 070.	Left turn 070 for downwind.
12 : 00	Descent	(estimated time of report only).	HFB reaching 1,500.
15 : 10	Initial Approach	HFB is cleared for base leg, make a left turn HDG 310.	Left turn 310 for base.
15 : 30	Initial Approach	HFB is cleared to ILS 25, report position OM.	Cleared to ILS 25, will report OM.
18 : 00	Final Approach	(estimated time of report only).	HFB position OM.
		Runway foaming finished (if foaming was requested), cleared for emergency landing.	Affirmative, cleared for emergency landing.
	Landing	-	-

Table 7: ATC instructions for ME scenario

TIME min sec	FLIGHT PHASE	ATC INSTRUCTION	PILOT'S RESPONSE
00 : 00	Cruise	HFB Experiment inception.	Affirmative.
04 : 10		INITIATION OF ENG N° II-FAILURE.	
04 : 20		(estimated time of report only).	Distress signal.
05 : 10	Cruise	HFB, Cologne weather is temporarily below minima, runway 25 is closed due to heavy snowfall, snow removal in progress for 10 minutes, standby for further information.	Affirmative.
06 : 10	Cruise	HFB is cleared for crosswind leg, make a left turn HDG 160.	Left turn 160 for crosswind.
07 : 10	Descent	HFB is cleared to 1,500 ft, report reaching 1,500.	Cleared to 1,500, will report reaching.
07 : 30		INITIATION OF HYDRAULIC SYSTEM FAILURE.	
07 : 50		(estimated time of report only).	Distress signal (reason, clearance request, etc.).
		HFB affirmative, standby for information.	
09 : 50	Descent	HFB is cleared for downwind leg, make a left turn HDG 070.	Left turn 070 for downwind.
12 : 00	Descent	(estimated time of report only).	HFB reaching 1,500.
14 : 30		HFB, Cologne weather: QNH as given, wind calm, visibility 10 +, runway 25 is clear and wet.	Thanks for the weather.
15 : 10	Initial Approach	HFB is cleared for base leg, make a left turn HDG 310.	Left turn 310 for base.
15 : 30	Initial Approach	HFB is cleared to ILS 25, report position OM.	Cleared to ILS 25, will report OM.
18 : 00	Final Approach	(estimated time of report only).	HFB position OM.
		Runway foaming finished (if foaming was requested), cleared for emergency landing.	Affirmative, cleared for emergency landing.
	Landing	-	-

C. Experimental Procedures

During the experimental flights, the pilot was sitting inside the mockup of the HFB-320 simulator which has been described in Appendix A. Two experimenters were necessary to run the experiments. They were sitting outside the mockup and communicated with the pilot via an intercom audio set. As shown in Figure 3, experimenter 1 was responsible for the ATC instructions and navigational information as explained in Appendix B whereas experimenter 2 gave the queries for depth of planning. A large clock served as a timer and was observed by the experimenters for a precise time-shared cooperation. The highest priority was devoted to asking the queries with equal time distances (see also

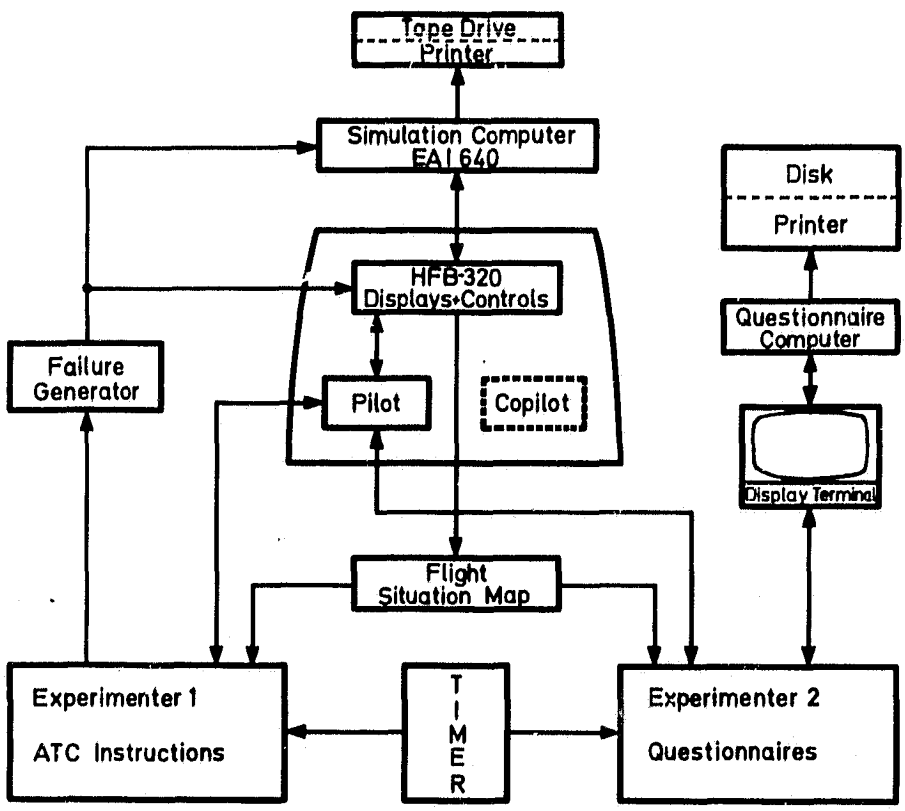

Figure 3: Experimental block diagram

Section 2.4.1). The ATC instructions were fitted into the intervals between the queries. However, urgent requests by the pilot were answered immediately.

The order of the flight phases and subtasks for depth of planning were presented to experimenter 2 by a questionnaire computer and shown on a display terminal (see Figure 3). The answers of the pilot were entered via this terminal into the computer by experimenter 2. Queries and answers were stored on disk and printed as a protocol.

The simulation computer was used for the HFB-320 flight simulation and for the acquisition of performance data (see Figure 3). The time functions which were sampled every 200 ms and stored on tape are shown in Table 8. Also, the performance tolerances mentioned in Section 2.4.4 are included in Table 8. In addition, binary information on discrete events of the simulated flights was collected within one special word of the computer; this was also updated every 200 ms (see Table 9).

Experimenter 1 was additionally responsible for initiating the failures during the emergency scenarios (see Figure 3). The flight situation map drawn by an x-y-plotter outside the mockup was used by the experimenters for monitoring the flights online and as a quick-look protocol.

All experiments lasted one day for each subject. First, the subjects became familiarized with the special features of the flight simulator by briefing and practicing as well as with the instructions for the experiment. The instructions were written in the pilot's native language, i.e., German. Also, the pilots answered a questionnaire concerning their flight experience. Further, the subjects responded to subjective scales for criticality, thereby getting acquainted with the flight phases and their subtasks and answering the question how critical these are to overall mission success. Then, the tests (T_1 through T_8 in Experiment I and T_1 through T_{11} in Experiment II) were performed.

Table 8: Time functions and performance tolerances measured during simulated flights

Variable	Explanation	
WEG X	x-coordinate in map	
WEG Y	y-coordinate in map	
TETAG	pitch angle	
FIG	roll angle	
H	altitude	
V	indicated airspeed	
PSIG	heading	
R	turn rate	
HP	vertical speed	
DEVGS	vertical deviation from landing path	
DEVLOC	horizontal deviation from landing path	
ITAKT	computer-cycle (40 ms)	
COCKPI	special word (see Table 9)	
ENGOFF	engine no. II status (operating or failing)	
XI	deflection of aileron control surface	
ETA	deflection of elevator control surface	
ZETA	deflection of rudder control surface	
TETAG	pitch angle	at H=0 — performance tolerances
FIG	roll angle	at H=0 — performance tolerances
X	longitudinal position	at H=0 — performance tolerances
Y	lateral position	at H=0 — performance tolerances
HPALT	sink rate	at H=0 — performance tolerances
DEVGS	glideslope deviation	at H=200 ft — performance tolerances
DEVLOC	localizer deviation	at H=200 ft — performance tolerances

After each test, the pilots estimated their experienced workload for each of the flight phases using the appropriate subjective scales. The whole experimental session ended for each pilot with a final interview in which he was asked to express his experiences with the experiment and to comment on some elements of his behavior observed by the experimenters.

All the instructions, off-line questionnaires, and subjective scales used in the experiments are included in Appendix E.

Table 9: Binary signals measured during simulated flights (stored in one special word; COCKPI)

Variable	Explanation
AP ENG	autopilot engaged
VS HLD	flight director mode: maintains vertical speed
FD OFF	flight director turn-off-signal
LOC CPT	flight director mode: localizer beam capture + track
ζ_{TR+}	movement of rudder trim tab: right deflection
ζ_{TR-}	movement of rudder trim tab: left deflection
ξ_{TR+}	movement of aileron trim tab: right deflection
ξ_{TR-}	movement of aileron trim tab: left deflection
ALT HLD	flight director mode: maintains barometric altitude
ATS ON	automatic throttle system engaged
STRT RGHT	indicates starter function of starboard engine
STRT LFT	indicates starter function of port engine
GEAR DN	indicates extended gear position
SPLR OUT	indicates extended spoiler position
η_{K0}	binary coded flap position: low bit
η_{K1}	binary coded flap position: high bit

D. Instructions and Final Interview in English*)

Experiment II, January 1981

INSTRUCTIONS
for the execution of flight experiments in the HFB-320 simulator

You have been so kind as to be willing to take part in our experiments in the simulator.

We ask you to make several 20 minute flights including landing with different experimental conditions. Rest periods have been scheduled sufficiently. We are interested to know how you prepare as a pilot for a given flight course before and during a flight, how you think ahead or act spontaneously, how much free play you can find for your own decisions, and how you work out solutions for unforeseen situations. The results of these investigations should give us a first indication how pilots plan their flight guidance and control tasks. Such knowledge is an important basis for the design and the evaluation of future instrumentations (e.g., CDTI = Cockpit Displayed Traffic Information) and other computer-aided planning support.

As far as we know, an investigation like this has not been executed at all until now. On the other hand, there seems generally to be great interest in our investigation as discussions at Lufthansa and NASA showed. Therefore, we ask you to support us with your frank criticism as extensively as possible. Every hint due to your experience may help us. Between the separate experimental flights, there will be an

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*) It should be noted that the actual written material employed was in German (see Appendix E). This translation is included for the benefit of non-German speaking readers.

opportunity for critique and discussion. All data and hints will be used only for scientific purposes and will not be passed on. There is no test situation in the whole experimental program.

Circling flight

Before starting the essential experiments, you shall first become acquainted with our flight simulator of the HFB-320. Now you could, e.g., start, make a circling flight, and land again - just as you like it.

CIRCLING FLIGHT

Questionnaire about flight experience

We ask you, now, to give us some information concerning, e.g., the number of your flight hours.

FILL OUT QUESTIONNAIRE

Flight course

With the help of a map, Mr. Hillmann will explain the given flight course to you. The flight course has been divided into 8 flight phases:

Cruise,
Descent,
Holding,
Initial Approach,
Final Approach,
Landing,
Ground Roll,
Cruise to Alternate.

In the simulator you will find an approach-flight map.

During the experimental flights, Mr. Hillmann will give you the necessary instructions for the approach procedure. He assumes the role of the air traffic controller as well as the role of the co-pilot for you - however, both over the intercom audio set.

Two different levels of automation will be chosen, namely

manual, i.e., without autopilot	always with Flight Director and Autothrottle
autopilot, i.e., with autopilot	

Before each experimental test, you will be informed about the level of automation to be actually flown. The flap position 20° shall principally remain unchanged during all tests.

During some tests, you have to expect unforeseen events. Please, understand that we cannot give further information thereon. Master the situation as you would do it in practice. You have complete decision freedom within the possibilities of our simulator and the instructions given to you. Also herewith, Mr. Hillmann is at your disposal as air traffic controller and co-pilot.

Immediately after each test, we want to know how you rate your subjectively experienced workload during the separate flight phases. Please, cross-mark the workload scales correspondingly.

LOOK AT SCALES

Questionnaire Technique

We want to conceive in our investigation how pilots act, think ahead, and plan. In order to find this out from you, we have invented a questionnaire technique.

The flight course has been divided into 8 flight phases. We shall ask you during all further tests over the intercom audio set about a certain flight phase or an associated subtask in a random order with intervals of about 20 seconds. Then, you shall answer as quick as possible (as far as the flight situation allows) how intensively you have been thinking about the respective flight phase or subtask. The queries will be interspersed by Mr. Johannsen between the flight guidance communication with Mr. Hillmann. Please, give your answers coded by numbers, as will be explained below.

You shall familiarize yourself, now, with the flight phases and the selected subtasks by means of a table. We ask you to cross-mark on always one scale how important, in your opinion, each individual flight phase and subtask is relative to the accomplishment of the overall mission, i.e., the <u>complete</u> flight course.

CROSS-MARK SCALES

During the flight tests, there are 10 possible answers for you to the query

> "Are you thinking at the moment (or were you thinking during the last 20 seconds) about the flight phase or subtask just mentioned"?

The answers are associated with the numbers 1 to 10, approximate[illegible] the following scheme:

Depth of Planning ↓		To what extent are you planning with respect to the flight phase or subtask?
	1	NOT AT ALL
	2	
	3	GENERALLY AWARE OF TASK
	4	
	5	OVERALL QUALITATIVE ASSESSMENT ONLY
	6	
	7	
	8	SPECIFIC INFORMATION NEEDS
	9	
	10	CONSIDERING SPECIFIC ACTIONS

In order to save time and to disturb you as little as possible during the accomplishment of your flight task, only the respective flight phase or subtask will be named with the queries and it will be dispensed with the repetition of the complete text of the queries. Due to the same reasons, please respond only with the numbers associated with the answers. Therefore, you should remember the table very carefully. Thereby, please understand the table as a coarse scheme with the response possibilities 1 to 10. The associated text explanations are not to be taken literally but shall only illustrate how you penetrate from 1 to 10 deeper and deeper into the planning tasks. With your answers, please take care of using the whole scale from 1 to 10.

After you have read these instructions completely, we will familiarize you in a short pre-test with the questionnaire technique. Thereby, we ask you to fly with the level of automation "Manual".

We ask you to accept patiently the queries as necessary additional communication. Give your answers as quick as possible. However, it has to be pointed out explicitly that flying is the more important task for you. If you must, therefore, respond slower, because you just have much to do, then this is absolutely okay. Should you have once no time at all for an answer, say "No" or "Nein". We shall continue also in that case with our queries as intended.

And now, enjoy the tests and many thanks for your participation.

Finally, a SOLICITATION to you:

Pass on no information about our tests to other pilots. Your colleagues shall come to us with the same status of information which you had. You can easily imagine that pre-information would be troublesome.

Many thanks.

PRE-TEST

FINAL INTERVIEW

Pilot: Date: Time:

1. Did you feel disturbed by our additional queries during your flight task?

2. Did you give your answers automatically or after some consideration (thinking)?

3. Did you give your answers as you would give them in daily flight operation or did you feel an artificial test situation?

4. Do your answers characterize more

	the actual execution	or	the mental anticipation
of subtasks (actions)	%		%
of flight phases (plans)	%	normal	%
	%	emergency	%

5. Did our queries comprehend the essential subtasks of the flight mission?

6. About what tasks or problems did you think very intensively during the flights without our asking about it?

7. During which flights have you produced most of all planning effort? Give a rank order where 1 means most effort.

		automatic	manual	
normal		☐	☐	
abnormal		☐	☐	☐ (abnormal + emergency, manual)
emergency	engine failure	☐	☐	
	hydraulic failure	☐	☐	

8. Did your planning occur more automatically (by rote, R) or after some consideration (thinking, T)?
   Enter the letter R or T:

		automatic	manual	
normal		☐	☐	
abnormal		☐	☐	
emergency	engine	☐	☐	☐
	hydraulic	☐	☐	

9. Do you consider routine or conscious planning the more important?

10. Were the flights at the beginning or at the end of the experimental sequence harder for you?

11. How would you judge our experiments all together?

12. Could you imagine practical possibilities of application?

13. What has annoyed you particularly?

14. Would you like to take part in further experiments?

A. Did your attitude with respect to our investigation or your understanding of it change during the experiments, e.g., due to experience? Did you answer differently at the end of the experimental sequence as compared to the beginning?

B. Have you seized the structure of our questionnaire scheme?

C. Do there exist (in your opinion) no, little, medium or great individual differences between pilots concerning the planning behavior?
   Of what kind are these differences?

E. Instructions, Questionnaires, and Final Interview in German

Experiment I, Dezember 1979/Januar 1980

INSTRUKTIONEN

zur Durchführung von Flugversuchen im HFB-320 Simulator

Sie haben sich freundlicherweise bereit erklärt, an unseren Versuchen im Simulator teilzunehmen.

Wir bitten Sie, mehrere etwa halbstündige Flüge einschließlich Landung mit unterschiedlichen Versuchsbedingungen durchzuführen. Erholungspausen sind in ausreichendem Maße vorgesehen. Uns interessiert, wie Sie sich als Pilot vor und während eines Fluges auf einen vorgegebenen Flugverlauf einstellen, wie weit Sie vorausdenken oder spontan handeln, wieviel Spielraum Sie für eigene Entscheidungen finden können und wie Sie Lösungen für unvorhergesehene Situationen erarbeiten. Die Ergebnisse dieser Untersuchungen sollen uns einen ersten Anhalt geben, wie Piloten ihre Flugführungsaufgaben planen. Derartige Kenntnisse sind wichtige Voraussetzungen für den Entwurf und die Bewertung zukünftiger Instrumentierungen (z.B. CDTI = Cockpit Display Traffic Information) und andere rechnergestützte Planungshilfen.

Nach unserem Wissen ist eine Untersuchung wie die vorliegende noch nirgendwo durchgeführt worden. Andererseits scheint grundsätzlich ein großes Interesse an unserem Vorhaben zu bestehen wie Gespräche bei der Lufthansa und der NASA zeigten. Aus diesen Gründen bitten wir Sie, uns mit Ihrer offenen Kritik möglichst weitgehend zu unterstützen. Jeder Hinweis aufgrund Ihrer Erfahrungen kann uns helfen. Zwischen den einzelnen Flugversuchen wird Gelegenheit zur Kritik und zum Gespräch sein. Alle Daten und Hinweise werden nur für wissenschaftliche Zwecke benutzt und nicht weitergegeben. Im gesamten Versuchsprogramm liegt keine Testsituation vor.

Platzrunde

Vor den eigentlichen Versuchen sollen Sie sich zunächst mit unserem Flugsimulator der HFB-320 vertraut machen. Sie können jetzt z.B. starten, eine Platzrunde fliegen und wieder landen - ganz nach Ihrem Belieben.

PLATZRUNDE

Fragebogen über Flugerfahrung

Wir bitten Sie jetzt, uns einige Informationen zur Anzahl Ihrer Flugstunden usw. zu geben.

FRAGEBOGEN AUSFÜLLEN

Flugverlauf

Der vorgegebene Flugverlauf wird Ihnen anhand einer Landkarte von Herrn Hillmann erläutert. Der Flugverlauf ist in die 7 Flugphasen

Cruise,
Descent,
Holding,
Initial Approach,
Final Approach,
Landing,
Ground Roll

unterteilt worden.

Herr Hillmann wird Ihnen während der Flugversuche die notwendigen Anweisungen für das Anflugverfahren geben. Er übernimmt für Sie sowohl die Rolle des Fluglotsen als auch die des Copiloten - beides jedoch über die Wechselsprechanlage.

Für die Versuche werden zwei verschiedene Automatisierungsstufen gewählt, nämlich

M	Manuell, d.h. ohne Autopilot	immer mit Flight Director
A	Autopilot, d.h. mit Autopilot	

Vor jedem Versuch wird Ihnen die jeweils zu fliegende Automatisierungsstufe mitgeteilt.

Bei einigen Versuchen müssen Sie mit unvorhergesehenen Ereignissen rechnen. Bitte haben Sie Verständnis dafür, daß wir Ihnen darüber keine weiteren Informationen geben können. Meistern Sie die Situation so, wie Sie es auch in der Praxis tun würden. Sie haben im Rahmen der Möglichkeiten unseres Simulators und der Ihnen gegebenen Anweisungen völlige Entscheidungsfreiheit. Herr Hillmann steht Ihnen auch hierbei als Fluglotse und Copilot zur Verfügung.

Unmittelbar nach jedem Versuch möchten wir wissen, wie Sie Ihre subjektiv empfundene Beanspruchung während der einzelnen Flugphasen einschätzen. Bitte kreuzen Sie entsprechend die Beanspruchungsskalen an.

Im ersten Versuch bitten wir Sie nun, den vorgegebenen Flugverlauf mit der Automatisierungsstufe M (Manuell) zu erfliegen.

1. VERSUCH

Befragungsmethode

Wir wollen in unserer Untersuchung erfassen, wie Piloten handeln, vorausdenken und planen. Um dies von Ihnen zu erfahren, haben wir uns eine Befragungsmethode ausgedacht.

Der Flugverlauf ist in 7 Flugphasen unterteilt. Wir werden Sie bei nahezu allen weiteren Versuchen in Abständen von etwa 30 Sekunden (gelegentlich seltener) über die Wechselsprechanlage in zufälliger Reihenfolge nach einer bestimmten Flugphase fragen. Sie sollen uns dann möglichst schnell (soweit es die Flugsituation erlaubt) antworten, wie intensiv Sie an die jeweilige Flugphase gedacht haben. Die Fragen werden von Herrn Johannsen zwischen die Flugführungskommunikation mit Herrn Hillmann eingestreut. Ihre Antworten geben Sie bitte als Ziffern verschlüsselt, wie weiter unten erläutert wird.

In einzelnen Fällen werden Sie zusätzlich nach maximal 3 Teilaufgaben pro Flugphase befragt. Diese Fragen erfolgen immer gebündelt unmittelbar eine nach der anderen. Zum Abschluß eines derartigen Fragenkomplexes wird "What else?" gefragt. Sie erhalten damit Gelegenheit, uns stichwortartig mitzuteilen, mit welchen Planungs- oder Denkaufgaben Sie während der letzten halben Minute sehr stark beschäftigt waren - nach denen wir Sie aber nicht direkt gefragt hatten. Wenn Sie keine derartige Mitteilung zu machen haben, antworten Sie z.B. "Nichts", "Nothing" oder ähnliches.

Sie sollen sich jetzt anhand einer Tabelle mit den Flugphasen und Teilaufgaben vertraut machen. Wir bitten Sie, auf je einer Skala anzukreuzen, wie wichtig nach Ihrer Meinung jede einzelne Flugphase bzw. Teilaufgabe in bezug auf die Erfüllung der Gesamtmission, d.h. den gesamten Flugverlauf, ist.

SKALEN ANKREUZEN

Es gibt für Sie während der Flugversuche 5 mögliche Antworten auf die Frage

> "Denken Sie im Augenblick (oder dachten Sie während der letzten halben Minute) an die jeweils angesprochene Flugphase bzw. Teilaufgabe?"

Die Antworten sind den Ziffern 1 bis 5 nach folgendem Schema zugeordnet:

Planungstiefe ↓		Denken Sie an Flugphase bzw. Teilaufgabe?
	1	ÜBERHAUPT NICHT
	2	NEHME GANZ ALLGEMEIN AUFGABE WAHR
	3	NUR QUALITATIVE GESAMTEINSCHÄTZUNG
	4	BESTIMMTE INFORMATIONSBEDÜRFNISSE
	5	ERWÄGE BESTIMMTE HANDLUNGEN

Um Zeit zu sparen und Sie bei der Durchführung Ihrer Flugführungsaufgabe so wenig wie möglich zu stören, wird bei den Fragen nur die jeweilige Flugphase bzw. Teilaufgabe genannt und auf die Wiederholung des vollständigen Fragentextes verzichtet. Aus denselben Gründen antworten Sie bitte nur mit der den Antworten zugeordnete Ziffer. Sie müßten sich die Tabelle daher sehr genau einprägen. Verstehen Sie dabei die Tabelle bitte als grobes Schema mit den Antwortmöglichkeiten 1, 2, 3, 4 oder 5. Die zugeordneten Texterläuterungen sind nicht wörtlich zu nehmen, sondern sollen nur verdeutlichen, wie Sie von 1 bis 5 immer tiefer in die Planungsaufgaben eindringen. Achten Sie bitte bei Ihren Antworten darauf, daß die gesamte Skala von 1 bis 5 verwendet werden soll.

Unmittelbar nach jeder Antwort Ihrerseits schließt sich eine Frage mit der Kurzform "Zunahme der Schwierigkeit?" an. Dahinter verbirgt sich folgende ausführliche Frage:

> "Erwarten Sie, ausgehend von der gegenwärtigen Situation und dem Flugzustand, eine Zunahme der Schwierigkeit bei der Durchführung der zuletzt angesprochenen Aufgabe bzw. bei der Nutzung der angesprochenen Information über das Normalmaß der Schwierigkeit hinaus?"

Wir meinen damit nicht, ob Sie mit der aktuellen Situation und dem Flugzustand zufrieden sind. Es interessiert nur eine mögliche Auswirkung der gegenwärtigen Situation und des Flugzustands im Hinblick auf die zuvor angesprochene Flugphase bzw. Teilaufgabe.

Auf die Frage nach der erwarteten Zunahme der Schwierigkeit haben Sie ebenfalls 5 mögliche Antworten. Sie nennen bitte wieder nur die zugeordnete Ziffer nach dem folgenden Schema:

	Erwartete Zunahme der Schwierigkeit?
1	KEINE
2	GERINGER
3	MÄSSIG
4	BETRÄCHTLICH
5	SEHR BETRÄCHTLICH

Wir bitten Sie, die Befragung als notwendige zusätzliche Kommunikation gelassen hinzunehmen. Geben Sie uns alle Antworten möglichst schnell. Ausdrücklich sei jedoch darauf hingewiesen, daß das Fliegen für Sie die wichtigere Aufgabe ist. Wenn Sie also langsamer antworten müssen, weil Sie gerade viel zu tun haben, so ist das völlig in Ordnung. Sollten Sie einmal gar keine Zeit für eine Antwort haben, sagen Sie entweder "No" oder "Nein". Wir werden auch dann in beabsichtigter Weise mit unseren Fragen fortfahren.

Nun viel Spaß bei den weiteren Versuchen und vielen Dank für das Mitmachen.

VERSUCHE

Zum Schluß eine BITTE an Sie:

Geben Sie keine Informationen über unsere Versuche an andere Piloten weiter. Ihre Kollegen sollen mit dem gleichen Informationsstand, den Sie hatten, zu uns kommen. Sie können sich sicher leicht vorstellen, daß Vorinformationen stören würden.

Vielen Dank.

Experiment II, Januar 1981

INSTRUKTIONEN

zur Durchführung von Flugversuchen im HFB-320 Simulator

Sie haben sich freundlicherweise bereit erklärt, an unseren Versuchen im Simulator teilzunehmen.

Wir bitten Sie, mehrere etwa 20 Minuten dauernde Flüge einschließlich Landung mit unterschiedlichen Versuchsbedingungen durchzuführen. Erholungspausen sind in ausreichendem Maße vorgesehen. Uns interessiert, wie Sie sich als Pilot vor und während eines Fluges auf einen vorgegebenen Flugverlauf einstellen, wie weit Sie vorausdenken oder spontan handeln, wieviel Spielraum Sie für eigene Entscheidungen finden können und wie Sie Lösungen für unvorhergesehene Situationen erarbeiten. Die Ergebnisse dieser Untersuchungen sollen uns einen ersten Anhalt geben, wie Piloten ihre Flugführungsaufgaben planen. Derartige Kenntnisse sind wichtige Voraussetzungen für den Entwurf und die Bewertung zukünftiger Instrumentierungen (z.B. CDTI = Cockpit Displayed Traffic Information) und anderer rechnergestützter Planungshilfen.

Nach unserem Wissen ist eine Untersuchung wie die vorliegende noch nirgendwo durchgeführt worden. Andererseits scheint grundsätzlich ein großes Interesse an unserem Vorhaben zu bestehen wie Gespräche bei der Lufthansa und der NASA zeigten. Aus diesen Gründen bitten wir Sie, uns mit Ihrer offenen Kritik möglichst weitgehend zu unterstützen. Jeder Hinweis aufgrund Ihrer Erfahrungen kann uns helfen. Zwischen den einzelnen Flugversuchen wird Gelegenheit zur Kritik und zum Gespräch sein. Alle Daten und Hinweise werden nur für wissenschaftliche Zwecke benutzt und nicht weitergegeben. Im gesamten Versuchsprogramm liegt <u>keine</u> Testsituation vor.

Platzrunde

Vor den eigentlichen Versuchen sollen Sie sich zunächst mit unserem Flugsimulator der HFB-320 vertraut machen. Sie können jetzt z.B. starten, eine Platzrunde fliegen und wieder landen - ganz nach Ihrem Belieben.

PLATZRUNDE

Fragebogen über Flugerfahrung

Wir bitten Sie jetzt, uns einige Informationen zur Anzahl Ihrer Flugstunden usw. zu geben.

FRAGEBOGEN AUSFÜLLEN

Flugverlauf

Der vorgegebene Flugverlauf wird Ihnen anhand einer Landkarte von Herrn Hillmann erläutert. Der Flugverlauf ist in die 8 Flugphasen

Cruise,
Descent,
Holding,
Initial Approach,
Final Approach,
Landing,
Ground Roll,
Cruise to Alternate

unterteilt worden.

Eine Anflugkarte liegt für Sie im Simulator bereit.

Herr Hillmann wird Ihnen während der Flugversuche die notwendigen Anweisungen für das Anflugverfahren geben. Er übernimmt für Sie sowohl die Rolle des Fluglotsen als auch die des Copiloten - beides jedoch über die Wechselsprechanlage.

Für die Versuche werden zwei verschiedene Automatisierungsstufen gewählt, nämlich

Manuell, d.h. ohne Autopilot Autopilot, d.h. mit Autopilot	immer mit Flight Director und Autothrottle

Vor jedem Versuch wird Ihnen die jeweils zu fliegende Automatisierungsstufe mitgeteilt. Die Klappenstellung 20° soll in allen Versuchen grundsätzlich unverändert bleiben.

Bei einigen Versuchen müssen Sie mit unvorhergesehenen Ereignissen rechnen. Bitte haben Sie Verständnis dafür, daß wir Ihnen darüber keine weiteren Informationen geben können. Meistern Sie die Situation so, wie Sie es auch in der Praxis tun würden. Sie haben im Rahmen der Möglichkeiten unseres Simulators und der Ihnen gegebenen Anweisungen völlige Entscheidungsfreiheit. Herr Hillmann steht Ihnen auch hierbei als Fluglotse und Copilot zur Verfügung.

Unmittelbar nach jedem Versuch möchten wir wissen, wie Sie Ihre subjektiv empfundene Beanspruchung während der einzelnen Flugphasen einschätzen. Bitte kreuzen Sie entsprechend die Beanspruchungsskalen an.

SKALEN ANSCHAUEN

Befragungsmethode

Wir wollen in unserer Untersuchung erfassen, wie Piloten handeln, vorausdenken und planen. Um dies von Ihnen zu erfahren, haben wir uns eine Befragungsmethode ausgedacht.

Der Flugverlauf ist in 8 Flugphasen unterteilt. Wir werden Sie bei allen weiteren Versuchen in Abständen von etwa 20 Sekunden über die Wechselsprechanlage in zufälliger Reihenfolge nach einer bestimmten Flugphase oder einer zugehörigen Teilaufgabe fragen. Sie sollen uns dann möglichst schnell (soweit es die Flugsituation erlaubt) antworten, wie intensiv Sie an die jeweilige Flugphase bzw. Teilaufgabe gedacht haben. Die Fragen werden von Herrn Johannsen zwischen die Flugführungskommunikation mit Herrn Hillmann eingestreut. Ihre Antworten geben Sie bitte als Ziffern verschlüsselt, wie weiter unten erläutert wird.

Sie sollen sich jetzt anhand einer Tabelle mit den Flugphasen und den ausgewählten Teilaufgaben vertraut machen. Wir bitten Sie, auf je einer Skala anzukreuzen, wie wichtig nach Ihrer Meinung jede einzelne Flugphase bzw. Teilaufgabe in bezug auf die Erfüllung der Gesamtmission, d.h. den gesamten Flugverlauf, ist.

SKALEN ANKREUZEN

Es gibt für Sie während der Flugversuche 10 mögliche Antworten auf die Frage

> "Denken Sie im Augenblick (oder dachten Sie während der letzten 20 Sekunden) an die jeweils angesprochene Flugphase bzw. Teilaufgabe?"

Die Antworten sind den Ziffern 1 bis 10 nach folgendem Schema näherungsweise zugeordnet:

Planungstiefe

	Denken Sie an Flugphase bzw. Teilaufgabe?
1	ÜBERHAUPT NICHT
2	
3	NEHME GANZ ALLGEMEIN AUFGABE WAHR
4	
5	NUR QUALITATIVE GESAMTEINSCHÄTZUNG
6	
7	
8	BESTIMMTE INFORMATIONSBEDÜRFNISSE
9	
10	ERWÄGE BESTIMMTE HANDLUNGEN

Um Zeit zu sparen und Sie bei der Durchführung Ihrer Flugführungsaufgabe so wenig wie möglich zu stören, wird bei den Fragen nur die jeweilige Flugphase bzw. Teilaufgabe genannt und auf die Wiederholung des vollständigen Fragentextes verzichtet. Aus denselben Gründen antworten Sie bitte nur mit der den Antworten zugeordneten Ziffer. Sie müßten sich die Tabelle daher sehr genau einprägen. Verstehen Sie dabei die Tabelle bitte als grobes Schema mit den Antwortmöglichkeiten 1 bis 10. Die zugeordneten Texterläuterungen sind nicht wörtlich zu nehmen, sondern sollen nur verdeutlichen, wie Sie von 1 bis 10 immer tiefer in die Planungsaufgaben eindringen. Achten Sie bitte bei Ihren Antworten darauf, daß die gesamte Skala von 1 bis 10 verwendet werden soll.

Nachdem Sie diese Instruktionen vollständig gelesen haben, werden wir Sie in einem kurzen Vorversuch mit der Befragungsmethode vertraut machen. Dabei bitten wir Sie, mit der Automatisierungsstufe Manuell zu fliegen.

Wir bitten Sie, die Befragung als notwendige zusätzliche Kommunikation gelassen hinzunehmen. Geben Sie uns alle Antworten möglichst schnell. Ausdrücklich sei jedoch darauf hingewiesen, daß das Fliegen für Sie die wichtigere Aufgabe ist. Wenn Sie also langsamer antworten müssen, weil Sie gerade viel zu tun haben, so ist das völlig in Ordnung. Sollten Sie einmal gar keine Zeit für eine Antwort haben, sagen Sie entweder "No" oder "Nein". Wir werden auch dann in beabsichtigter Weise mit unseren Fragen fortfahren.

Nun viel Spaß bei den Versuchen und vielen Dank für das Mitmachen.

Zum Schluß eine BITTE an Sie: Geben Sie keine Informationen über unsere Versuche an andere Piloten weiter. Ihre Kollegen sollen mit dem gleichen Informationsstand, den Sie hatten, zu uns kommen. Sie können sich sicher leicht vorstellen, daß Vorinformationen stören würden. Vielen Dank.

VORVERSUCH

Fragebogen über Flugerfahrung

Name:

Alter:

Welche Fluglizenzen haben Sie?

Anzahl der Flugstunden insgesamt?

Anzahl der Flugstunden auf der HFB-320?

Anzahl der Flugstunden auf anderen Flugzeugtypen?

Typ	Anzahl

Sind Sie überdurchschnittlich viel auf Simulatoren geflogen?
Wenn ja, auf welchen?

Bemerkungen Ihrerseits:

Danke.

Pilot:

Bitte ankreuzen:

Wie wichtig (im Sinne von besser aufpassen) ist jede der folgenden Flugphasen bzw. Teilaufgaben in bezug auf die Erfüllung der <u>Gesamt</u>mission?

völlig unwichtig — sehr wichtig	
____________________	1. Cruise
____________________	1.1 Approach procedure
____________________	1.2 Request to leave flight level
____________________	1.3 Fuel control (+ Power setting)
____________________	2. Descent
____________________	2.1 Obstacle clearance
____________________	2.2 Flight instruments
____________________	2.3 Altimeter
____________________	3. Holding
____________________	3.1 Track intercept
____________________	3.2 Traffic orders (+ information)
____________________	3.3 ATIS (e.g., runway condition, weather, QNH)
____________________	4. Initial Approach
____________________	4.1 Flaps
____________________	4.2 Localizer intercept
____________________	4.3 Glideslope intercept
____________________	5. Final Approach
____________________	5.1 Gear
____________________	5.2 Weather minima
____________________	5.3 Flare

völlig unwichtig	sehr wichtig	
		6. Landing (Flare + Touchdown)
		6.1 Crosswind
		6.2 Runway condition
		6.3 Passenger comfort
		7. Ground Roll (after Landing)
		7.1 On centerline
		7.2 Speed-brakes
		7.3 Flaps
		8. Cruise to alternate
		8.1 Approach procedure
		8.2 Request to leave flight level
		8.3 Fuel control (+ Power setting)

Beanspruchungsskalen

Pilot: VNr.: Datum: Uhrzeit:

Wie stark fühlten Sie sich durch die Arbeitsbelastung subjektiv beansprucht? Geben Sie die Antworten bitte getrennt für die 7 Flugphasen durch Ankreuzen der folgenden Skalen.

Cruise	sehr geringe Beanspr.	geringe Beanspr.	eher geringe Beanspr.	mittlere Beanspr.	eher hohe Beanspr.	hohe Beanspr.	sehr hohe Beanspr.
Descent	sehr geringe Beanspr.	geringe Beanspr.	eher geringe Beanspr.	mittlere Beanspr.	eher hohe Beanspr.	hohe Beanspr.	sehr hohe Beanspr.
Holding	sehr geringe Beanspr.	geringe Beanspr.	eher geringe Beanspr.	mittlere Beanspr.	eher hohe Beanspr.	hohe Beanspr.	sehr hohe Beanspr.
Initial Approach	sehr geringe Beanspr.	geringe Beanspr.	eher geringe Beanspr.	mittlere Beanspr.	eher hohe Beanspr.	hohe Beanspr.	sehr hohe Beanspr.
Final Approach	sehr geringe Beanspr.	geringe Beanspr.	eher geringe Beanspr.	mittlere Beanspr.	eher hohe Beanspr.	hohe Beanspr.	sehr hohe Beanspr.
Landing	sehr geringe Beanspr.	geringe Beanspr.	eher geringe Beanspr.	mittlere Beanspr.	eher hohe Beanspr	hohe Beanspr.	sehr hohe Beanspr.
Ground Roll	sehr geringe Beanspr.	geringe Beanspr.	eher geringe Beanspr.	mittlere Beanspr.	eher hohe Beanspr.	hohe Beanspr.	sehr hohe Beanspr.

Abschluß-Interview

Pilot: Datum: Uhrzeit:

1. Fühlten Sie sich durch unsere zusätzliche Befragung bei Ihrer fliegerischen Aufgabe gestört?

2. Gaben Sie Ihre Antworten automatisch oder mit einigem Nachdenken?

3. Gaben Sie Ihre Antworten, wie Sie sie auch im täglichen Flugbetrieb geben würden, oder empfanden Sie eine künstliche Testsituation?

4. Kennzeichnen Ihre Antworten eher

	die aktuelle Ausführung	oder	die gedankliche Vorausnahme
von Teilaufgaben (Handlungen)	%		%
von Flugphasen (Plänen)	%	normal	%
	%	Notfall	%

5. Wurden die wesentlichen Teilaufgaben der Flugmission durch unsere Fragen erfaßt?

6. An welche Aufgaben oder Probleme dachten Sie während der Flüge besonders intensiv, ohne daß wir danach fragten?

7. Bei welchen Flügen haben Sie nach Ihrer Meinung am meisten Planungsaufwand getrieben? Geben Sie eine Rangreihe, wobei 1 am meisten Aufwand bedeutet.

		automatisch	manuell	
normal		☐	☐	
außergewöhnlich		☐	☐	
Notfall	Triebwerksausfall	☐	☐	☐
	Hydraulikfehler	☐	☐	

8. Erfolgte Ihre Planung eher automatisch (routinemäßig, R) oder mit einigem Nachdenken (N)?
   Tragen Sie die Buchstaben R oder N ein:

		automatisch	manuell	
normal		☐	☐	
außergewöhnlich		☐	☐	
Notfall	Triebwerk	☐	☐	☐
	Hydraulik	☐	☐	

9. Halten Sie Routine oder bewußte Planung für wichtiger?

10. Waren die Flüge am Anfang oder die am Ende der Versuchsreihe anstrengender?

11. Wie würden Sie unsere Experimente insgesamt beurteilen?

12. Können Sie sich praktische Anwendungsmöglichkeiten vorstellen?

13. Was hat Sie besonders geärgert?

14. Würden Sie an weiterführenden Experimenten gern teilnehmen?

A. Hat sich während der Versuche Ihre Einstellung zu unserer Untersuchung bzw. das Verständnis dafür, z.B. aufgrund von Erfahrung, geändert? Haben Sie am Ende der Versuchsreihe anders geantwortet als am Anfang?

B. Haben Sie erfaßt, wie unser Befragungsschema aufgebaut ist?

C. Bestehen nach Ihrer Meinung keine, geringe, mittlere oder große individuelle Unterschiede zwischen Piloten bezüglich des Planungsverhaltens?
   Welcher Art sind sie?